| | |
|---|---|
| Antenna Size (m) | .33<br>.66 |
| Antenna Gain (dBi) | 39<br>44 |
| Antenna 3 dB Beamwidth (degrees) | 1.7<br>1 |
| Antenna Polarization | H/V |
| Receiver Noise Figure (dB) | 8 |

[1] The selected FS example is a point-to-point system.

The total assumed FS link budget was defined as a means to accommodate effects of probable self (FS) and external (FSS) interference into a victim FS system while maintaining the required system performance in a rain/atmospheric absorption dominated propagation environment. Based on the starting condition of a minimum [C + C/I] threshold of -149.5 dBW/MHz for BER = 1 x $10^{-6}$ and 99.999% availability over a 2.9 km link, a radio interference budget of 2 dB was established by reducing the assumed link distance to 2.3 km to obtain adequate signal margin to overcome an assumed level of radio interference from all sources, while maintaining the desired FS system threshold availability and BER derived from the rain attenuation model set forth above in Section 3. The resulting 2 dB radio interference margin was then allocated to self (FS) and external (FSS) interference on a 90% / 10% basis respectively. See Recommendation ITU-R F.1094-1. This results in 1.8 dB being allocated to FS self-interference and .2 dB for all FSS interference sources.

Based on the allocated radio interference and attenuation budgets, the [C + C/(I+N)] requirement is now -147.5 dBW/MHz (-149.5 dBW/MHz + 2 dB = -147.5 dBW/MHz) which will allow the interference to degrade the desired signal by 2 dB to -149.5 dBW/MHz and still maintain the specified minimum threshold performance in the rain-dominated propagation environment. The ability to accommodate rain and other atmospheric attenuation and radio interference separately in a link budget is considered critical to overall FS performance and availability objectives, given the propagation environment.

The next step was to determine the interference power levels that would cause .2 dB and 1.8 dB increase in the C + C/(I + N) threshold.

The resulting threshold interfering power levels for self and FSS interference are:

Self: $I \leq$ -152.4 dBW/MHz for 1.8 dB increase

FSS $I \leq$ -162.8 dBW/MHz for .2 dB increase

**B. Potential FSS Interference Into FS Receivers**

**Single Entry Interference.** The potential for interference from FSS transmitters to an FS receiver was evaluated by calculating the total FSS interference power density at a victim FS receiver and comparing it to the interference budget. A single entry FSS into FS sidelobe coupling event resulting from the normal assumed operations of the representative NGSO FSS constellation and a representative victim FS system was evaluated.

For the analysis, the representative NGSO FSS satellite was assumed to be at an elevation of 25° above the horizon, and emitting a signal with the maximum power flux density allowed in Article 28 of the Radio Regulations (-105 dBW/m$^2$ in a 1 MHz bandwidth). See RR 2578, RR 2582, RR 2583 & RR 2584.

The received interfering signal resulting from this coupling case was assumed to be noiselike, have no polarization mismatch loss, and to add cumulatively to the noise power in the receiver.

The received interference signal level from the FSS scenario was calculated assuming the power flux density limits described in RR 2578, the satellite elevation angles above the horizon, and capture area of the FS antenna utilizing Equation 3. The gain of the FS antenna was determined utilizing the maximum elevation angle, given reasonable deployment assumptions, corresponding to the 2.3 km link presented in Section 4 (8°).

$$I_{FSS} = P_d + G_R - 20 \text{ Log } f + 38.5 \qquad \text{Equation 3}$$

where $I_{FSS}$ = FSS interfering signal power
$P_d$ = FSS power flux density at angles $\geq 25°$ (-105 dBW/m$^2$ in a 1 MHz bandwidth)
$G_R$ = FS receiver antenna gain, 12 dBi
f = FS frequency, 40 GHz

Based on Equation 3, the received FSS interference power at the FS receiver is computed to be 146.5 dBW/MHz.

The worst case situation for FS receiver interference susceptibility occurs when the FS signal is fully faded due to rain attenuation. This is the condition reflected in the link budget presented above. For the purposes of this analysis, it was assumed that the FSS signal was also faded. The FSS signal was reduced by 6.8 dB to account for fading due to rain attenuation as assumed in the representative NGSO system proposal. The resulting FSS interfering power level at the FS receiver was computed to be 153.3 dBW/MHz after accounting for bandwidth, and fading factors.

The radio interference budget for a fully faded FS signal allows the FSS interference to be

-162.8 dBW/MHz for no impact. The FSS single entry case exceeds this threshold by 9.5 dB, which in turn reduces the available C + C/(I+ N) from -149.5 dBW/MHz to 148.0 dBW/MHz. This will have the effect of increasing the BER of the modeled FS link under heavy rain-faded conditions. Under unfaded conditions on the FSS path, the interfering FSS signal will reduce the available FS fade margin from 49.7 dB to 48.2 dB, and thus reduce the availability of the FS link. It should be noted that the degradation of FS link margins resulting from FSS downlink interference will be mitigated by increases in link margin that result from shorter FS path lengths.

**Multiple Entry Interference.** Multiple entry FSS space-to-Earth mainbeam-to-sidelobe interference events into a victim FS receiver are readily probable in the case of a single representative interfering NGSO FSS constellation. For the representative NGSO FSS single constellation configuration, multiple entry interference can be modeled by assuming up to three FS sidelobe coupled interfering mainbeam FSS signals entering the FS antenna from an elevation of 22° above the horizon. According to a representative NGSO FSS system proposal, most of CONUS will see two satellites all of the time, and a portion of CONUS will see three satellites up to 75% of the time.

The likelihood of multiple entry FSS into FS interference events also increases substantially when two co-channel NGSO FSS constellations are assumed. This assumption can be based on a satellite diversity FSS to FSS network sharing scheme to effectuate co-channel operations by the subject NGSO FSS constellations. Such a two constellation NGSO FSS model was proposed by the proponent of the representative NGSO FSS system. The resulting multiple entry interference scenario could involve upwards of 130 NGSO FSS satellites. Thus, it can be assumed that up to six FSS mainbeam into FS sidelobe cases could occur simultaneously.

Interference levels for the single representative NGSO FSS constellation multiple entry case could be 3 - 5 dB higher than the single entry case.

The predicted interference power from the two NGSO FSS constellation multiple entry scenario will result from up to six FS sidelobe coupled signals, and, thus, will present at least a 3 dB worse interference condition than the single constellation case.

### C. FS Interference Into FSS Earth Station Receivers

Based on the system deployment model indicated for NGSO FSS networks, NGSO FSS earth station receivers are likely to be deployed to address many of the same service applications and, often, in many of the same locations that FS systems are utilized. Since the desired locations of many FS systems are, by definition, flexible and unpredictable prior to actual deployment, and the desired locations of the FSS earth station receivers are often likely not to be known in advance, potential interference from an FS transmitter to an FSS earth station receiver was evaluated by computing a required distance separation for several coupling conditions. The coupling conditions that were evaluated were FS sidelobe-to-FSS mainbeam, FS mainbeam-to-FSS sidelobe, and FS sidelobe-to-FSS sidelobe paths. In addition, two FSS sidelobe antenna gain levels were evaluated. The first ("S/L-1")

corresponds to the level presented in a representative NGSO system, and the second ("S/L-2") corresponds to a low sidelobe level implementation of the same antenna.

The pertinent FSS earth station receiver characteristics that were used for this analysis are listed in Table 2. These characteristics were obtained from the representative NGSO FSS system proposal used for the FSS into FS interference study. The selected representative DS-3 FS transmitter characteristics are listed in Table 1.

**Table 2**
**REPRESENTATIVE PROPOSED NGSO FSS SPACE-TO-EARTH CHARACTERISTICS**

| | |
|---|---|
| Frequency Range (GHz) | 37.5 - 40.5 |
| Antenna Gain (dBi) | M/B: 54.4<br>S/L-1: -1.5<br>S/L-2: -4.5 |
| Receiver Thermal Noise Level (dBW/Hz) | -201.6 |
| Required $I_0/N_0$ (dB) | -10.5 |

The required propagation path loss ($L_R$) and corresponding distance separation (d) between an FS transmitter and NGSO FSS earth station receiver for the three coupling cases was determined using Equations 4 and 5.

$$L_R = P_T + G_T + G_R - (I_0/N_0) - N_0 \qquad \text{Equation 4}$$

where $P_T$ = FS transmitter power, -92 dBW/Hz
$G_T$ = FS antenna gain in direction of FSS receiver, dBi
$G_R$ = FSS receiver antenna gain in direction of FS transmitter, dBi
$I_0/N_0$ = FSS Receiver degradation criteria, -10.5 dB
$N_0$ = FSS Receiver thermal noise level, -201.6 dBW/Hz

$$L_R = 20 \text{ Log}(f) + 20 \text{ Log}(d) + A(d) - 27.6 \qquad \text{Equation 5}$$

where f = FS frequency, 40 GHz
d = Required distance separation (meters)
A = Atmospheric absorption ($H_2O$, $O_2$), .00015 dB/m

As a worst case scenario the FS signal was assumed to not be faded for the calculations and the FSS space-to-Earth transmission path was assumed to be fully faded. This is reflected in the FSS space-to-Earth maximum interference power threshold in Table 3. The signals were also assumed to be co-polarized. The results of the application of Equations 4 and 5 are shown in Table 3 for the three coupling cases cited above.

**Table 3**
**RESULTS OF FS TO FSS REQUIRED DISTANCE SEPARATION CALCULATIONS**

| Antenna Coupling | FS Transmitter Antenna Gain ($G_T$) (dBi) | FSS Receiver Antenna Gain ($G_R$) (dBi) | Required Loss ($L_R$) (dB) | Required Distance Separation (d) |
|---|---|---|---|---|
| FS M/B to FSS S/L | 44 | S/L-1: -1.5<br>S/L-2: -4.5 | S/L-1: 162.6<br>S/L-2: 159.6 | S/L-1: 40.4 km<br>S/L-2: 32.5 km |
| FS S/L to FSS M/B | 4[1/] | 54.4 | 178.6 | 96.6 km |
| FS S/L to FSS S/L | 4[1/] | S/L-1: -1.5<br>S/L-2: -4.5 | S/L-1: 122.6<br>S/L-2: 119.6 | S/L-1: 800 m<br>S/L-2: 570 m |

[1/] Measured value at 30° off-axis angle

### D. FS Multiple Entry Interference Into FSS Earth Station Receivers

The single-entry FS DS-3 link that was chosen for purposes of this study is an optimistic test case for the analysis of FS interference into FSS earth station receivers. Higher spectral densities produced by FS DS-1 systems with a transmitter power of 17 dBm in a 5 MHz bandwidth are likely to cause higher levels of interference into FSS receivers at greater distances than the level of interference produced by an FS DS-3 transmitter. Under current FS operational scenarios, there can be a very large number of DS-1 and DS-3 data rate links operating simultaneously at random locations and pointing angles within a given geographic area. Thus, multiple entry FS interference into FSS receivers is quite likely and will couple more interference power, at more antenna pointing angles into the victim FSS receivers. The effect of this will be to extend the period of time that an FSS receiver will experience degradation as it tracks satellites across the sky, making sharing extremely difficult. It is anticipated that higher data rate FS systems using more complex modulation schemes and substantially higher e.i.r.p. (up to 55 dBW e.i.r.p.) than current systems will be deployed at a rapid

pace in the near future. These developments will only serve to make FS/FSS sharing even more difficult.

## 4. SHARING BETWEEN FS AND FSS EARTH-TO-SPACE OPERATIONS

### A. Representative FS and FSS System Parameters

The parameters used for the selected representative 47.2 -50.2 GHz FS and FSS systems are shown below in Tables 4 & 5.

**Table 4**
**CHARACTERISTICS OF REPRESENTATIVE 47.2 - 50.2 GHz DS-1 FS SYSTEM[1/]**

| | |
|---|---|
| Data Rate/Capacity | DS-1 |
| Frequency Range (GHz) | 47.2 - 50.2 |
| Modulation Type | 2 FSK |
| Necessary Bandwidth (MHz) | 5 |
| Transmitter Power (dBM) | 19 |
| Transmit e.i.r.p. (dBW) | 35 |
| e.i.r.p. density | 28.01 dBW/MHz<br>-31.99 dBW/Hz |
| Receiver Sensitivity (dBW)<br>(BER 1 x $10^{-6}$) | -122 |
| Antenna Size (m) | .66 |
| Antenna Gain (dBi) | 46 |
| Antenna 3 dB Beamwidth (degrees) | 0.7 |
| Antenna Polarization | H/V |
| Receiver Noise Figure (dB) | 11 |

[1/] The selected FS example is a point-to-point system.

| Table 5<br>REPRESENTATIVE PROPOSED NGSO FSS<br>EARTH-TO-SPACE CHARACTERISTICS | |
|---|---|
| Frequency Range | 47.2 - 50.2 GHz |
| Main Beam Gain (dBi) | 49.3 |
| Sidelobe Gain (dBi) | $G = 32.25 \log \theta$ |
| Data Rate (Mbps) | 10.24 |
| Modulation type | QPSK |
| Necessary bandwidth (MHz) | 10.24 |
| Transmit Power (dBW) | 1.26 |
| Transmit e.i.r.p. (dBW) | 50.6 |
| Antenna polarization | circular |
| Receiver Thermal Noise Level (dBW/Hz) | -201.6 |
| Required $I_0/N_0$ (dB) | -13 dB |

**B. FS Interference Into FSS Space Station Receivers**

Using the representative DS-1 FS parameters, it can be observed that harmful interference will only be experienced when an NGSO FSS space station passes within, or close to, the FS transmitter main beam. With the assumed representative FS e.i.r.p. level of 35 dBW, and a resulting e.i.r.p spectral density of 28.01 dBW/MHz, when the FS station transmits at an angle of 22° above the horizon, the $I_0/N_0$ = - 0.17 dB. This is approximately 13 dB above the interference threshold of $I_0/N_0$ = - 13 dB. This result is based on the computed distance to the victim satellite space station receiver of 2585.5 km with a combined path loss and atmospheric absorption of - 208.27 dB.

It should be noted that the representative DS-1 FS system, which is typical of types now in service. has a receiver input threshold level of -122 dBW, while upcoming 16 QAM and 256 QAM FS systems require -106 and -94 dBW respectively (i.e., an increase in 16 and 28 dB respectively). It

can therefore be seen that FS e.i.r.p. levels will of necessity be required to move towards the 55 dBW maximum value in order to provide satisfactory long term performance.

When comparing the representative peak e.i.r.p. density of 28.01 dBW/MHz with a recently proposed limit of 51-11(0-15)/2, (at 22° this is 12.5 dBW/MHz) the difference of 15.5 dB, which is the amount of e.i.r.p. reduction that is being proposed for the FS. However, if the proposed e.i.r.p. limit is imposed on the FS, besides having a deleterious impact on long term system performance and development, it will also cause the FS system to become more susceptible to FSS earth station interference.

### C. FSS Earth Station Interference Into FS Receivers

For purposes of analyzing potential FSS earth station interference into FS receivers, it is assumed that the worst case interference into the FS network occurs when the FSS earth station is transmitting towards a space station at its minimum 22° working elevation angle. This would be the condition under which the maximum sidelobe interference would be encountered. An example case is evaluated below.

| | |
|---|---|
| <u>FSS Transmitting Parameters At 0°</u> | |
| Sidelobe gain at 22° off main beam | - 1.56 dBi |
| Sidelobe e.i.r.p. | - 0.3 dBW |
| Sidelobe spectral density | - 10.4 dBW/MHz<br>- 70.4dBW/Hz |
| <u>FS Receive Parameters</u> | |
| Rx noise figure | 11 dB |
| System Noise Temperature | 3660 K |
| $N_0$ = | -192.98 |
| Off boresight angle | 0° |
| Antenna diameter | .66 |
| Antenna gain (dBi) | 46.0 dBi |
| $I_0$ | -205.98 dBW/Hz |
| $I_0/N_0$ | -13.0 dB |

| Path Parameters | |
|---|---|
| Path loss | 181.58 dB |
| Absorption | 21.8 dB |
| Attenuation | 159.8 dB |
| Required separation distance from NGSO earth station | 54.6 km radius |

## 5. INTERFERENCE MITIGATION TECHNIQUES

Following is a discussion of possible techniques that may be considered as methods to mitigate interference into FSS earth station receivers from FS operations.

**Automatic Transmitter Power Control.** FS automatic transmitter power control ("ATPC") has been suggested as a means to facilitate sharing with FSS earth station receivers. This method would entail reducing the FS e.i.r.p. by an amount corresponding to some portion of the signal margin designed into the FS link budget to overcome fading due to rain attenuation. ATPC could be effective during periods when the fade margin is not required to reduce somewhat the required distance separation between FS transmitters and FSS receivers. However, rain-induced attenuation will often not be correlated with respect to FS interferers and both FS and FSS victim receiving stations, rendering ATPC ineffective, and even counterproductive to the provision of service. Because of the uncorrelated fading problem, the application of ATPC is very likely to increase rather than decrease interference into adjacent victim receivers, thus totally defeating any marginal benefit that might be derived from the its application as an interference mitigation technique.

ATPC will substantially increase the cost and complexity of the FS systems and, thus, could jeopardize the commercial viability of FS services. A leading manufacturer of millimeter wave FS equipment has stated that ATPC is not a feature available on currently deployed equipment. If ATPC were to be implemented, it would be accomplished through the use of sensors with a reliable range of operation of 10 - 15 dB. To reliably control power over a wider range would require a completely different approach that would increase the cost of transmitters by an estimated 33 - 50%. It would also require time to implement in new equipment and retrofit into existing installations. This cost and time impact is unacceptable to the operators and manufacturers of FS equipment.

While ATPC may result in reduced distance separations between FS and FSS installations, it appears unlikely that the separation distance reduction afforded by ATPC will have any real measurable benefits for sharing between FS systems and FSS receivers. Even with the use of ATPC the resulting

required separation distances will be far in excess of a practical interservice coordination standard, given the defined operational objectives of the representative FS and FSS systems studied. In addition, the use of ATPC causes FS receivers to be more susceptible to FSS downlink interference. In Section 5, it was shown that FSS interference to FS receivers is minimal except when a maximum length FS link is fully faded due to rain. In this case FSS downlink interference into FS receiver antenna sidelobes will impact FS system performance. ATPC will effectively remove the signal margin that protects FS receivers from FSS downlink interference. FS transmitter power control causes the FS receiver to operate in a near fully faded condition all of the time with respect to the FSS downlink signal. The use of ATPC coupled with the high likelihood of multiple entry FSS interference will cause FS performance impacts to occur in less than fully faded conditions, or for links operating at less than maximum path lengths.

Assuming that it would be technologically feasible and economically rational to implement ATPC for purposes of facilitating compatibility with shared FSS operations, the added capability is likely to not protect the operation of both services equally. If it could be implemented, the amount of power control that is possible would depend on a trade-off between the allowable interference to FS receivers from downlink signals, and the minimum acceptable distance separation between FS transmitters and FSS earth stations for compatible operation. From Table 3 it can be seen that the amount of FS transmitter power reduction required to allow uncoordinated FSS earth station receivers for likely coupling conditions may approach or exceed the total margin available for a FS link. This coupled with the increased likelihood of FSS downlink interference associated with ATPC and the cost and time impacts makes power control unworkable.

**Diversity.** Spatial diversity has been proposed as a means to facilitate sharing between multiple NGSO FSS systems, and has also been suggested for aiding sharing between NGSO FSS systems and FS systems. This interference mitigation method relies on multiple satellites being able to simultaneously communicate with the same service point, such that a change of FSS earth station azimuth angle can be exploited to minimize interference.

The use of FSS spatial diversity may be effective in alleviating interference from traditional fixed service systems with pre-determined static system architectures. It does not appear, however, that this interference mitigation technique will be effective with respect to interference from FS systems, which regularly have links located randomly and pointing in random azimuths and elevation angles. It is quite likely that the ability of FSS systems utilizing spatial diversity to overcome interference from FS systems will be completely offset by the large probability of a FSS receiver that is reoriented to avoid a first FS interferer again being located in the interference area of a second FS transmitter.

**Shielding.** Various FSS earth station shielding methods have been employed in the past to facilitate coordination between traditional long-haul fixed service systems and FSS space-to-Earth operations. While such shielding has been effective in the past to some extent, it does not appear that the use of shielding would be practical as a means of negating the significant level of harmful interference likely to be experienced from nearby FS transmitters, which may be present in significant numbers. With power level differentials expected of more than 40 dB between the FS transmitters and FSS receivers, shielding of 10-15 dB may be readily achievable. However, any larger amount could require

significant time and effort, and the successful outcome would still be in doubt, given the ubiquitous deployment objectives characteristic of the representative NGSO FSS system and the operational characteristics inherent to FS.

## 6. CONCLUSIONS

For the cases analyzed in this study, the interference caused to an FS receiver by a single entry sidelobe coupling event resulting from the space-to-Earth operations of the representative NGSO FSS system degrades the FS link performance by 9.5 dB, and reduces the available C + C/(I+N) value by 1.5 dB for a fully faded FS link. Under non-faded conditions the FSS interference will reduce the available FS link fade margin by 1.5 dB. The impact of this condition is to potentially render a maximum length FS link unusable under fully faded conditions, to slightly reduce availability under fully faded conditions below the required performance level, or to require slightly shorter link lengths to maintain system performance. These effects will be mitigated by increased FS link margin resulting from shorter path lengths if FS e.i.r.p. is maintained.

The impact from multiple entry FSS space station transmitter interference into FS receivers is predicted to be 3 - 5 dB worse than the single entry case. However if a two constellation, multiple entry FSS interference scenario occurs, interactions from up to six sidelobe coupled FSS signals is possible, and could increase the predicted interference level by up to 6 - 8 dB.

Interference from FS transmitters to FSS earth station receivers was evaluated by determining required distance separations for several coupling conditions. The most likely coupling cases will be FS mainbeam-to-FSS sidelobe, and FS sidelobe-to-FSS mainbeam interactions. It can be seen from Table 3 and from defined FS and FSS operational objectives (i.e., rapid high-density deployment), that distances are far in excess of a practical interservice coordination standard, given the defined operational objectives of the representative FS and FSS systems studied. Advanced FS configurations that will be deployed in the near future are expected to utilize higher order modulation schemes, increased e.i.r.p. and/or dynamic bandwidth and antenna beamwidth capabilities. Thus, future FS systems could be even more susceptible to harmful interference from FSS space-to-Earth operations, or cause an even larger distance separation requirement for FSS earth station receivers than currently deployed FS systems.

Several potential interference mitigation schemes have been proposed as methods to minimize interference from FS transmitters into FSS earth stations. The use of FS automatic transmitter power control ("ATPC"), FSS earth station and/or space station diversity, and FSS earth station shielding are discussed in Section 5. Diversity and shielding may offer small gains in reducing interference, however the high-density, uncoordinated deployment requirements of both services minimize the potential for reducing interference.

The use of FS ATPC was proposed as a method of minimizing interference by reducing the required distance separations between FS transmitters and FSS earth stations. ATPC looks attractive initially, however there are several problems associated with it that render it ineffective. The amount of FS power control required to allow uncoordinated FSS operation approaches or exceeds the total FS

signal margin available. In addition, ATPC causes FS receivers to effectively operate in a fully faded condition relative to FSS downlink signals, which in combination with likely multiple entry coupling changes a minimal interference case into a more serious condition. Lastly, no current FS systems are equipped with power control capability, and the cost and time required to redesign, implement, and retrofit FS systems is very high and unacceptable. Furthermore, many cases of uncorrelated fading can occur between interfering FS stations and victim FSS stations, thus rendering the use of ATPC a highly unpredictable method of facilitating interference-free co-frequency operation.

As demonstrated in Section 4 of this study, the separation distances required to protect FS stations from transmitting earth station emissions in the 47.2 - 50.2 GHz band render prospects for viable co-frequency operations by FS and FSS systems impractical, given the assumed deployment objectives in the respective services. Use of an e.i.r.p. mask may prove effective to protect space station receivers from FS emissions, but will only serve to exacerbate the susceptibility of victim FS receivers to interference from earth station transmissions.

Accordingly, it is reasonable to conclude that co-frequency FS and FSS system operations in bands above 30 GHz are not operationally or economically feasible.

# ATTACHMENT 3

# ANNOTATED SECTION 4.3 OF TIA BULLETIN TSB10-F

Reproduced By GLOBAL
ENGINEERING DOCUMENTS
With The Permission of EIA
Under Royalty Agreement

# TIA/EIA TELECOMMUNICATIONS SYSTEMS BULLETIN

TSB10-F

## Interference Criteria for Microwave Systems

Excerpt from

**TSB10-F**

**(Revision of TSB10-E)**

**JUNE 1994**

**TELECOMMUNICATIONS INDUSTRY ASSOCIATION**

TELECOMMUNICATIONS INDUSTRY ASSOCIATION
Representing the telecommunications industry in association with the Electronic Industries Association

consider the overall system noise objectives in parallel with the system reliability (outage) objectives. Most analog links require significant carrier level increases above threshold sensitivity just to achieve acceptable baseband signal-to-noise (*e.g.* >35 dB increase for 70 dB S/N in the worst message channel in an FM-FDM link).

## 4.3 Automatic Transmit Power Control in Digital Links

### 4.3.1 Introduction:

Automatic (or Adaptive) Transmit Power Control (ATPC) is a desirable feature of a digital microwave radio link that automatically adjusts transmitter output power based on path fading detected at the far-end receiver(s). ATPC allows the transmitter to operate at less than maximum power for most of the time. When fading conditions occur, transmit power will be increased as needed. ATPC is useful for extending the life of transmitter components, reducing power consumption, simplifying frequency coordination in congested areas, allowing additional up-fade protection, and (in some radios) increasing the maximum power output (improves system gain).

If the maximum transmit power in a ATPC link is needed for only a short period of time, a transmit power less than maximum may (if certain restrictions are met) be used when interference calculations are made into other systems. Many years of fading statistics have verified that fading on different physical paths is non-correlated, *i.e.* the likelihood of two paths in a given area being in a deep fade and thus sensitive to interference simultaneously is very small. Further, to allow for inevitable deep fading, microwave paths are designed with unfaded carrier-to-noise (C/N) and carrier-to-interference (C/I) ratios much greater than those required for high quality path performance. Since fading is non-correlated among paths, a short-term power increase by a path experiencing a deep fade will not reduce the C/I on other paths to an objectionable level. On a properly designed path, and one not affected by rain outage, ATPC-equipped transmitters will be at maximum power for a short period of time. However, because the maximum power is available when deep fades occur, CFM, threshold C/N, and C/I calculations into an ATPC link may assume the "Maximum Transmit Power" receive carrier level.

ATPC has been successfully implemented in FCC Part 21 common carrier bands for several years, and, under FCC *ET Docket 92-9*, is now permitted under Part 94. Currently, there are two types of ATPC available. The "ramping" type increases power dB for dB with a fade greater than a certain depth. The "stepped" type increases power in a single step to maximum power when a fade exceeds a certain depth. Besides significantly aiding the frequency coordination process, ATPC also provides receiver up-fade overload protection due to the backed-off transmit power under normal signal level conditions.

### 4.3.2 ATPC recommendations for frequency coordination

During the coordination process, the ATPC user must clearly state that ATPC will be used. The transmit powers associated with an ATPC system included on the coordination notice are defined as follows:

| | |
|---|---|
| Maximum Transmit Power | That transmit power that will not be exceeded at any time, used for CFM and path reliability (outage) computations, and for calculating the C/I into an ATPC system. |
| Coordinated Transmit Power | That transmit power selected by the ATPC system licensee as the power to be used in calculating interference levels into victim receivers. |
| Nominal Transmit Power | That transmit power at or below the coordinated power at which the system will operate in normal, unfaded conditions. |

The Coordinated Transmit Power is restricted to a 0 to 10 dB range below the Maximum Transmit Power. The Nominal Transmit Power must be less than or equal to the Coordinated Transmit Power, with typical values ranging from 6 to 15 dB below the Maximum Transmit Power. The receive level at which the system either steps up or begins to increase (ramp up) the far-end transmit power (depending on the type of ATPC) is referred to as the ATPC Trigger Level. Because shallow fading characteristics are path dependent and unpredictable, at least a 10 dB fade must occur before the Coordinated Transmit Power is exceeded.

In order to claim a Coordinated Transmit Power less than the Maximum Transmit Power (ATPC feature is used), certain restrictions on the time that this power is exceeded must be met. Below about 12 Ghz, the expected annual time percentages should not exceed the limits shown in Figure 4-4 and provided in Table 4-2. These time percentages can be calculated by the applicable reliability calculations as shown in Section 4.2.3. First, the fade depth that causes the transmit power to exceed the Coordinated Transmit Power by a certain number of dB must be calculated. This fade depth is then substituted for the CFM in the reliability calculation. For a ramping ATPC system that uses a step increase in transmit power, a single calculation of the time that the fade depth to the ATPC trigger level is exceeded is all that is required. For an ATPC system that increases (ramps up the) power in a linear dB for dB fashion, calculations of the time that the Coordinated Transmit Power is exceeded and the time that the Maximum Transmit Power is reached are sufficient. Future ATPC systems that boost transmit power in some other way may require time percentage calculations for the entire range of transmit power in excess of the Coordinated Transmit Power.

Note: There is no provision for greater than 12 GHz.

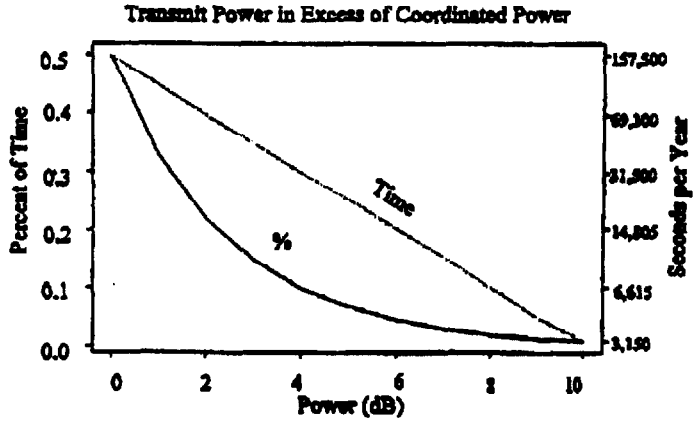


**Figure 4-4 — Permitted Time Above Coordinated Transmit Power**

In dB steps above the selected Coordinated Transmit Power for ramping-type ATPC systems, the permitted time percentages (and annual transmit power boost times) are shown in the following table. Only one single value ( +6, +10 dB, *etc.*) need be considered in step-type ATPC systems (see examples in Section 4.3.3).

| Power above Coordinated Transmit Power (dB) | Permitted time (annual) | |
|---|---|---|
| | Percentage of time | Seconds per year |
| 0.0 | 0.50 | 157,500 |
| 1.0 | 0.33 | 103,950 |
| 2.0 | 0.22 | 69,300 |
| 3.0 | 0.15 | 47,250 |
| 4.0 | 0.10 | 31,500 |
| 5.0 | 0.07 | 22,050 |
| 6.0 | 0.047 | 14,805 |
| 7.0 | 0.032 | 10,080 |
| 8.0 | 0.021 | 6,615 |
| 9.0 | 0.014 | 4,410 |
| 10.0 | 0.010 | 3,150 |

Table 4-2 — Time Permitted Above the Coordinated Transmit Power in an ATPC Link

$$Time = 100 \left( \frac{Time, sec}{31.5 \times 10^6} \right) \quad \% \qquad (4.3\text{-}1)$$

ATPC-equipped transmitters that claim a Coordinated Transmit Power less than the Maximum Transmit Power must base transmit power increases on path fading. In those cases, interference or error correcting information alone is not sufficient for increasing transmit power, but either or both may be used as an additional criterion. For systems with space diversity, ATPC must be controlled by the stronger signal from the two antenna system. In calculating the time percentages above Coordinated Transmit Power, the space diversity improvement factor may be found to be less than one if the fade depth is small. In these instances, a space diversity improvement factor of one may be assumed (no improvement or penalty from using space diversity).

ATPC-equipped transmitters must not be allowed to stay in the Maximum Transmit Power mode for more than any five minute duration. This event should result in an alarm condition which returns the transmit power to the Normal Transmit Power. ATPC should then not be re-enabled until a determination has been made that this long-term anomaly has been corrected and normal operation can be resumed. This criterion will prevent a long-term degradation, such as a down-stream receiver or control channel failure falsely implying a deep fade, from causing a transmitter to be in the Maximum Transmit Power mode for an extended period of time.

If the above restrictions are met, interference calculations from an ATPC system may assume the lower Coordinated Transmit Power level. Interference and CFM calculations into the receiver of an ATPC-equipped system can then assume that the Maximum Transmit Power is in use. Thus, in calculating performance (outage, etc.) and a C/I for comparison to the objectives, the "C" is then based on the Maximum Transmit Power.

When a Coordinated Transmit Power less than Maximum Transmit Power is claimed for an ATPC

system, documentation that the system will meet these recommendations should be supplied during the coordination process. Because rain fading, obstruction fading, or surface duct fading could cause an ATPC system to increase power for a much longer time, additional justification for claiming a Coordinated Transmit Power less than the Maximum Transmit Power may have to be provided for paths with inadequate clearance or long paths above about 10 GHz. Paths that do not meet the restrictions may still use ATPC, but a Coordinated Transmit Power equal to the Maximum Transmit Power must be used in the coordination process.

The cumulative yearly time at maximum transmit power and the maximum transmit power single duration event time of five minutes may not be appropriate for radios operating above about 12 GHz due to the impact of rain rates and duration on interference cases. Further study in this area is needed.

In order to best reflect ATPC operation in the licensing process, the transmit power shown in the FCC filing should be the Maximum Transmit Power of the station. The station EIRP corresponding to the Maximum Transmit Power must meet FCC EIRP requirements.

Note: ATPC is not recommended for use with analog radios because of the signal-to-noise degradation with the increase in thermal noise proportional to the normal transmitter back-off.

### 4.3.3 ATPC time above Coordinated Transmit Power sample calculations

In order to best reflect ATPC operation in the licensing process, the transmit power shown in the FCC filing should be the Maximum Transmit Power of the station. The following examples illustrate typical ATPC computations:

*Example 1: Ramping-type ATPC is to be used on a 40 km (25 mile) 6.7 GHz path without space diversity. The ATPC trigger level is -55 dbm. Once this trigger level is reached, the system will increase transmit power one dB for every additional dB of fade. The Nominal Transmit Power of the equipment is +14 dBm with a Maximum Transmit Power of +29 dBm. Average climate, terrain, and temperature conditions exist on the path. The path is designed for a receive level, with Nominal Transmit Power, of -43 dBm. The designer wishes to check if a Coordinated Transmit Power of +19 dBm, 10 dB below the Maximum Transmit Power, can be specified under the recommendations:*

*A fade depth of 12 dB from -43 to -55 dBm causes the trigger level to be reached. An additional 5 dB of fade boosts the power from +14 dBm to the +19 dBm Coordinated Transmit Power. The time that the fade depth exceeds 12+5=17 dB is computed to be:*

$$T = 20\,(6.7)\,(25)^3\,10^{-\left(\frac{17}{10}\right)} = 41{,}776 \text{ seconds} \qquad (4.3\text{-}2)$$

*or 0.1326 percent of the time, which meets the 0.5 percent requirement.*

*An additional 10 dB of fade will cause the transmitter to reach its +29 dBm Maximum Transmit Power. The time that the fade depth exceeds 17+10 = 27 dB is computed to be:*

$$T = 20\,(6.7)\,(25)^3\,10^{-\left(\frac{27}{10}\right)} = 4{,}178 \text{ seconds} \qquad (4.3\text{-}3)$$

*or 0.0133 percent of the time. This does not meet the requirement of 0.01 percent of the time for 10 dB above the Coordinated Transmit Power.*

*Since the power is allowed to exceed the Coordinated Transmit Power by as much as 9 dB for 0.014 percent of the time, a Coordinated Transmit Power of +20 dBm (9 dB below the Maximum Transmit Power) may thus be specified.*

*Example 2: ATPC equipment that increases power in a single step to Maximum Transmit Power is to be considered on the non-diversity path in the previous example. The Nominal Transmit Power is +24 dBm for a receive level of -33 dBm. The Maximum Transmit Power is +30 dBm and the ATPC trigger level is 10 dB above the $10^{-3}$ BER outage threshold of -74 dBm. The designer wants to check if a Coordinated Transmit Power equal to the Nominal Transmit Power can be specified under these rules:*

*The ATPC trigger level is -64 dBm (10 dB above the $10^{-3}$ BER threshold) and a fade depth of 31 dB from the nominal power receive level will cause this trigger level to be reached. The time that the fade depth exceeds 31 dB is computed to be:*

$$T_{SD} = 20\,(6.7)\,(25)^3\,10^{-\left(\frac{31}{10}\right)} = 1{,}663 \text{ seconds} \qquad (4.3\text{-}4)$$

*or 0.0053 percent of the time. Since a path is permitted to be 6 dB above the Coordinated Transmit Power (+24 boosted to +30 dBm) for 0.047 percent of the time, this path meets the requirement.*

*Example 3: A single-step ATPC'd transmitter is considered for a 48 km (30 mi) 6.7 GHz space diversity path with 9 m (30 ft) dish spacing. Average climate terrain and temperature conditions are present on the path. The Nominal (and Coordinated) Transmit Power is +20 dBm (+30 dBm maximum) for a -42 dBm nominal receive level. The ATPC trigger level is 10 dB above the -77 dBm $10^{-3}$ BER outage threshold, or -67 dBm.*

*The ATPC is thus triggered with both space diversity receivers faded from -42 dBm to -67 dBm, or 25 dB. The time that the fade depths both exceed 25 dB is computed to be:*

$$T_{SD} = \frac{3 \times 10^5\,(30)^4\,10^{-\left(\frac{25}{5}\right)}}{30^2} = 2{,}700 \text{ sec} \qquad (4.3\text{-}5)$$

*or 0.0086 percent of the time. Since a path is permitted to be 10 dB above the Coordinated Transmit Power 0.01% of the time, this space diversity link meets the requirement.*