Appendix II

AMST Link Margin Analysis

Power consumption within the AMST is critical for long-term missions. Since power comsumption is maximum for transmit operations, investigations into the actual required effective isotropic radiated power (EIRP) for different AMST modes of operation were carried out and the findings are reported here. Of the many equipment scenarios possible, only the AMST-satellite-AMST case was considered.

Given the standard fading and polarization loss budgets which are generally adopted [A2.1], it was found that operationally, there was little real advantage in using a 20 W power amplifier (PA) over a 10 W PA when only short manpack whip antennas were being used. In most cases where the 10 W PA did not provide sufficient EIRP, the additional 3 dB obtained by employing a 20 W PA still did not provide sufficient link margin to permit reliable communications to take place.

Use of a +6 dBi antenna in place of the short whip antenna generally resulted in usable communication links with 10 W PAs even at data rates of 4800 bps. In contrast, the AMST is incapable of 25 kHz DAMA communications unless the =6 dBi antenna is adopted even with the use of a 20 watt power amplifier.

Analysis Details

The satellite parameters where were used for this study were adopted directly from reference [A2.1] and are provided in Table A2.1 below.

Table A2.1 Satellite Link Analysis Parameters
25 kHz Tranponders

Satellite	LEASAT	FLTSAT	UFO
Freq., MHz			
UpLink	297.95	297.85	297.00
DownLink	256.95	256.85	256.00
EIRP, dBW	26.0	26.0	26.0
G/T, dB	-18.0	-16.7	-18.0

5 kHz Transponders

EIRP, dBW	16.5	16.0	20.0
G/T, dB	-18.0	-16.5	-16.7

The fade and polarization losses used for this study are provided in Table A2.2 and were similarly adopted from reference [A2.1].

Table A2.1 Fading and Polarization Losses

Elevation, Deg	30	10	5
Fading, dB	3.0	5.0	6.0
Polarization, dB	0.5	0.5	0.5

Assuming a spherical satellite orbit and earth, the distance to the geostationary satellite positioned at an elevation angle of θ radians may be easily computed as

$$r = 6378\left[-\sin(\theta) + \sqrt{\sin^2(\theta) + 42.699303}\right] km \quad (1)$$

where r is the straight-line distance to the satellite, and the earth radius and orbit altitude were taken to be 6,378 and 35,784 km respectively.

The carrier-to-noise ratio (CNR) at the satellite receiver is given by

$$\frac{C_u}{N_u} = \frac{EIRP_u}{L_u L_{pu}} \frac{G_{sa}}{T_u} \frac{1}{k B} \quad (2)$$

where

$EIRP_u$	effective isotropic radiated power of the uplink transmitter
G_{sa}	satellite antenna gain
L_{pu}	uplink path loss
L_u	other miscellaneous uplink path losses
T_u	effective noise temperature of the satellite receiver
B	receiver bandwidth.

The u subscript denotes that these quantities pertain to the uplink. The uplink EIRP is given by

$$EIRP_u = C_t G_t \quad (3)$$

where C_t is the uplink tranmitted power and G_t is the antenna gain of the uplink transmit antenna. The free space path loss is given by

$$L_{pu} = \left(\frac{4\pi r f_u}{c} \right)^2 \quad (4)$$

where

r	link of sight distance to satellite, km
c	speed of light, km/s
f_u	uplink frequency, Hz

The minimum (earth-bound) distance to any geostationary satellite is 35,784 km, but as the elevation angle increases, the distance to the satellite increases as well which results in higher propagation loss.

The effect of hard-limiting within the satellite transponder contributes a net gain of 0.4 dB for signal-to-noise ratios (SNR) greater than 0 dB. This gain is denoted by G_s. Using this factor, the CNR at the satellite output is then given by

$$\frac{C_s}{N_s} = \frac{C_u}{N_u} G_s \quad (5)$$

Downlink Calculations

The downlink signal consists of carrier and noise signal components and each must be dealt with separately. The downlink carrier signal power received by the earth station antenna is given by

$$C_r = \frac{C_s\, G_{sa}}{L_d\, L_{pd}} G_r \quad (6)$$

where

C_s	satellite carrier power, W
G_{sa}	satellite antenna gain
L_{pd}	downlink path loss
L_d	miscellaneous downlink path losses
G_r	ground station receiver antenna gain

The noise power received by the earth station from the satellite is given by

$$N_r = \frac{N_s\, G_{sa}}{L_d\, L_{pd}}\, G_r = \frac{C_s N_u}{C_u\, G_s}\, \frac{G_{sa}}{L_d\, L_{pd}}\, G_r \qquad (7)$$

The ground station receiver-antenna contributes its own thermal noise which competes with the received signal, this noise being given by

$$N_d = k\, T_d\, B \qquad (8)$$

where T_d is the effective noise temperature of the ground station. Therefore, the total noise power referenced to the input of the ground station receiver is given by

$$N = N_r + N_d = \frac{N_u}{C_u}\, \frac{C_s}{G_s}\, \frac{G_{sa}}{L_d\, L_{pd}}\, G_r + k\, T_d\, B \qquad (9)$$

The total CNR at the ground station receiver input is then given by

$$\frac{C_r}{N} = \frac{\dfrac{C_s\, G_{sa}}{L_p\, L_{pd}}\, G_r}{\dfrac{N_u}{C_u}\, \dfrac{C_s}{G_s}\, \dfrac{G_{sa}}{L_d\, L_{pd}}\, G_r + k\, T_d\, B} \qquad (10)$$

Using the fact that the total power transmitted by the satellite is the sum of the carrier plus noise powers, P_s, following a bit of algebra, the ground station CNR may be expressed simply as

$$\frac{C_r}{N} = \frac{1}{[\, U^{-1} + D^{-1} \,]} \tag{11}$$

where

$$U = \frac{G_s\, C_u}{k\, T_u\, B}$$

$$D = \frac{EIRP_s}{k\, B} \left(\frac{G_r}{T_d}\right) \frac{1}{L_d\, L_{pd}} \frac{1}{1 + \dfrac{k\, T_u\, B}{C_u\, G_s}} \tag{12}$$

and U and D should be recognizable as the uplink and downlink CNRs respectively.

The required ground station E_b/N_o for a given bit error rate (BER) performance was based upon the normal error function curve for uncoded systems. In the case of coded systems, the rate 1/2, constraint length k=7 optimal convolutional code of Odenwalder [A2.2] was assumed having the bit error rate bound given by

$$P_b \le \frac{1}{2} [\, 36\, D^{10} + 211\, D^{12} + 1404\, D^{14} + 11633\, D^{16} + \dots \,] \tag{13}$$

where D is a function of the channel metric employed. For soft decisions, from [A2.2],

$$D = e^{-E_s/N_o} \tag{14}$$

where E_s is the energy per coded symbol. For rate R coding,

$$\begin{aligned} \frac{E_s}{N_o} &= \frac{E_b}{N_o} + 10\, Log_{10}(\, R \,) \\ &= \frac{E_b}{N_o} - 3\ dB \quad for\ R = 1/2 \end{aligned} \tag{15}$$

Based upon this approach, the required downlink CNR versus BER performance levels have been summarized in Table A2.3.

Table A2.3 Required Downlink CNR vs. BER (BPSK or QPSK)

BER	Uncoded E_b/N_o, dB	Uncoded CNR, dB	Coded E_b/N_o, dB	Coded CNR, dB
10^{-3}	6.8	6.8	3.15	0.14
10^{-5}	9.6	9.6	4.65	1.64

Two different antenna cases were considered in this analysis, a short linearly polarized impedance-matched dipole without a reflector, and a +6 dBi circularly polarized high-gain antenna. The short dipole antenna typically displays a gain of 1.76 dB over isotropic, but due to the circular polarization loss of 3 dB, the net antenna gain for this case is reduced to -1.24 dBi. The high-gain antenna was assumed to be simply +6 dBi.

Link Margin Results: 25 kHz DAMA

A short computer program was written based upon the preceding formula to investigate the trade-offs between AMST EIRP and G/T when operating AMST-satellite-AMST communication links. The analysis results which are provided in graphical form here are summarized in Table A2.4.

Table A2.4 AMST G/T Vs. EIRP Trade-Offs @ 10^{-5} BER

Fig	Satellite	Elev.	25k/5k	Data Rate	Coding
A2.1	LEASAT	30	5k	600 bps	1/2
A2.2	LEASAT	5	5k	600	1/2
A2.3	UFO	30	25k	2400	1/2
A2.4	UFO	10	25k	2400	1/2
A2.5	UFO	5	25k	2400	1/2
A2.6	UFO	5	5k	2400	1/2
A2.7	UFO	30	5k	2400	1/2
A2.8	LEASAT	5	5k	4800	1/2
A2.9	LEASAT	30	5k	4800	1/2
A2.10	UFO	5	5k	4800	1/2
A2.11	UFO	30	5k	4800	1/2
A2.12	LEASAT	5	25k	4800	1/2
A2.13	LEASAT	10	25k	4800	1/2
A2.14	LEASAT	30	25k	4800	1/2

The first question considered addressed the ability of the AMST to communicate within a 25 kHz DAMA network using only the small dipole antenna. The following assumptions were made:

Data Rate	9600 bps	(minimum for 25 kHz DAMA)
Coding	Rate 1/2	
BER	10^{-5}	

Receiver Noise Figure	4 dB
Input Sky Temperature	150°
Antenna	Short dipole
Net Receiver G/T	-28.93 dB

Based upon these assumptions, it was found that DAMA operation was only possible for optimistic elevation angles (30° or larger) even with a 20 W transmitter PA regardless of the satellite involved. Both uplink and downlink quality factors contributed to this result. Dropping the BER requirement to 10^{-3} from 10^{-5} did not change this conclusion. In conclusion, the high-gain antenna is required in order for the AMST to reliable communicate with 25 kHz DAMA nets.

Link Margin Results: 5 kHz Transponders

The analysis program was run extensively assuming 4800 bps, rate 1/2 coding and BERs of 10^{-5} and 10^{-3} to evaluate the AMST's performance with 5 kHz DAMA networks. For the 3 elevation angles and 3 satellites considered (a total of 9 combinations), only the UFO satellite at 30 degrees elevation case had adequate link margin to support communications with a short dipole antenna at each AMST. In contrast, reliable communication was easily accomplished with the +6 dBi antennas and the same case parameters as shown in Table A2.5.

Table A2.5 Required Carrier Power for AMST Equipped with +6 dBi Antenna at 10^{-5} BER, 4800 bps, R= 1/2

	Elevation Angle, Deg		
Satellite	30	10	5
LEASAT	2.24 W	6.3 W	11.2 W
FLTSAT	1.78	5.0	8.9
UFO	1.33	2.66	4.0

Here again, moving to a 20 W transmitter was insufficient for conducting communications whereas the +6 dBi antenna was able to close the links with substantially less than 20 W.

Similar calculations were performed for 1200 bps and 10^{-5} with both AMSTs using a short dipole antenna and rate 1/2 coding. The required transmitter power for the same case matrix is shown in

Table A2.6. Here again, reliable communication generally required 10 watts or less, or more than 20 watts.

Table A2.6 Required Carrier Power for AMST Equipped with Short Dipole Antenna at 10^{-5} BER, 1200 bps, R= 1/2

	Elevation Angle, Deg		
Satellite	30	10	5
LEASAT	4.20 W	10.6 W	> 20 W
FLTSAT	2.60	9.4	> 20
UFO	1.90	4.2	5.9

Conclusions

The AMST could greatly benefit from having a transmit power level control capability since under most situations, considerably less than 20 Watts is required from the PA. This would automatically lead to extended mission life, lower intercept probability, and reduce spectral contamination in cosite operations.

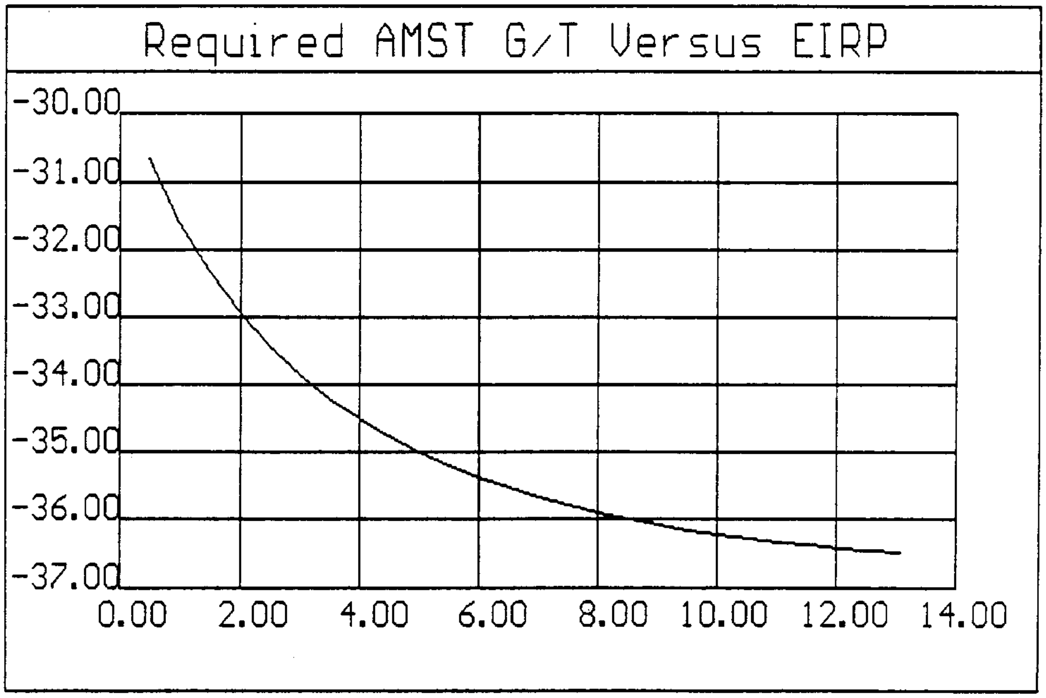

Figure A2.1 (G/T), dB Versus $EIRP_u$, dBW
LEASAT @ 30°, 5k Trans., 600 bps

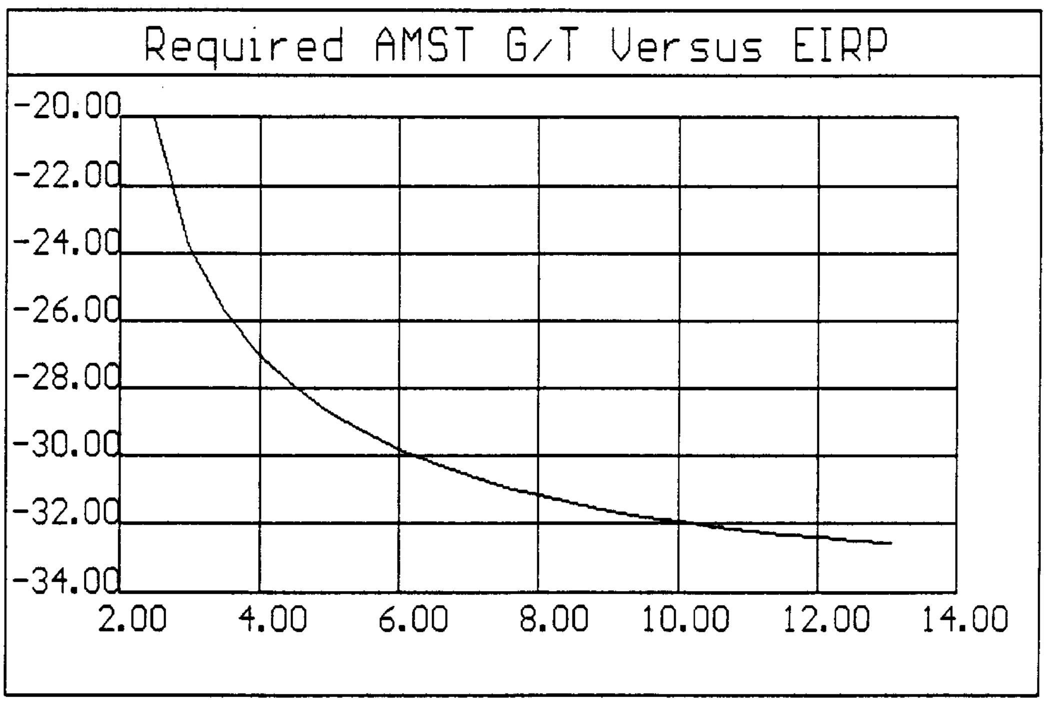

Figure A2.2 (G/T), dB Versus $EIRP_u$, dBW
LEASAT @ 5°, 5k Trans., 600 bps

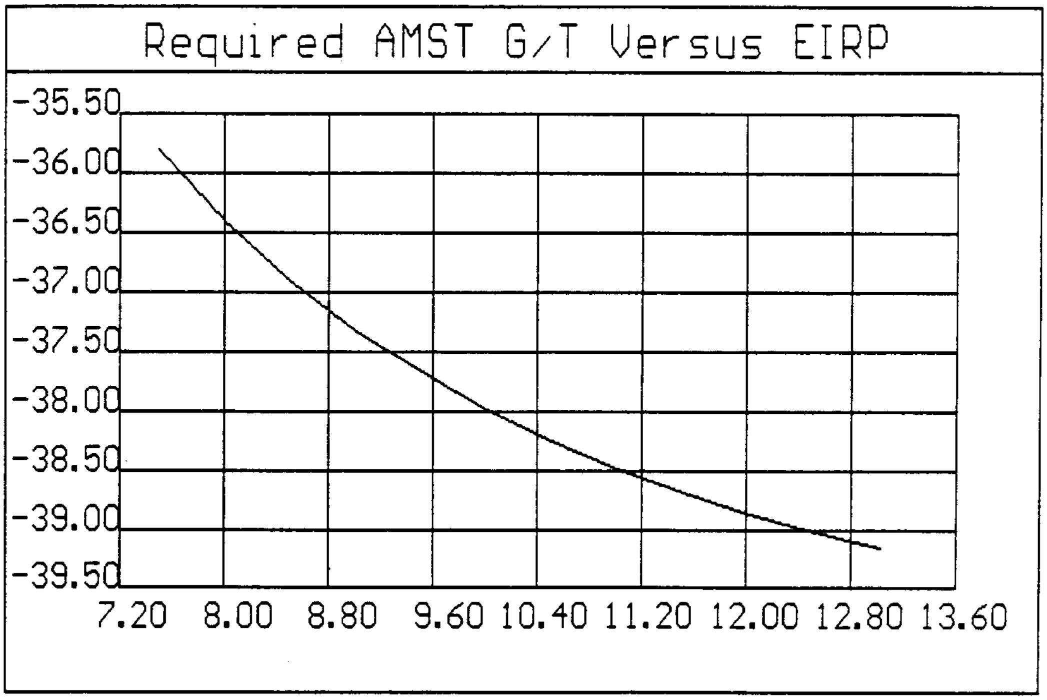

Figure A2.3 (G/T), dB Versus EIRP$_u$, dBW
UFO @ 30°, 25k Trans., 2400 bps

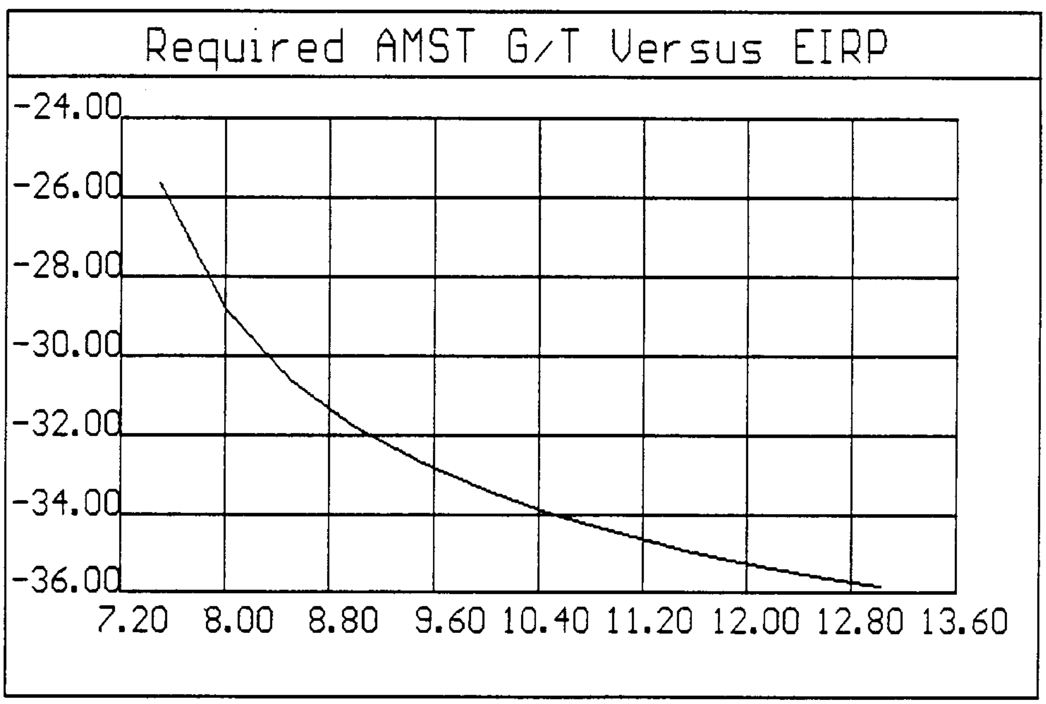

Figure A2.4 (G/T), dB Versus EIRP$_u$, dBW
UFO @ 10°, 25k Trans., 2400 bps

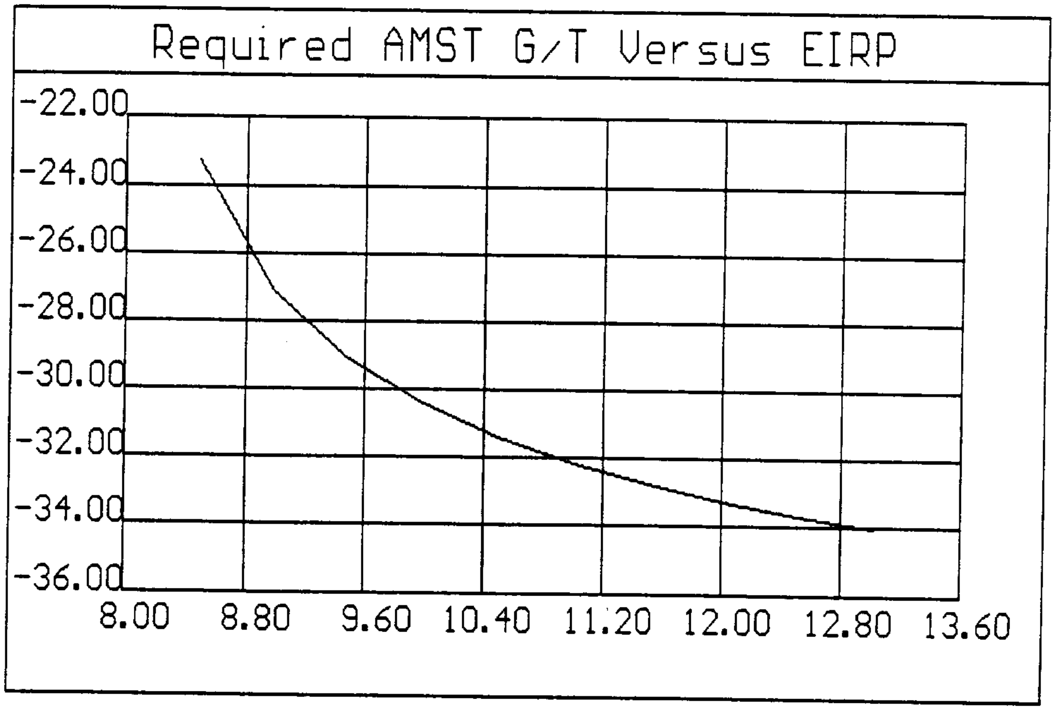

Figure A2.5 (G/T), dB Versus $EIRP_u$, dBW
UFO @ 5°, 25k Trans., 2400 bps

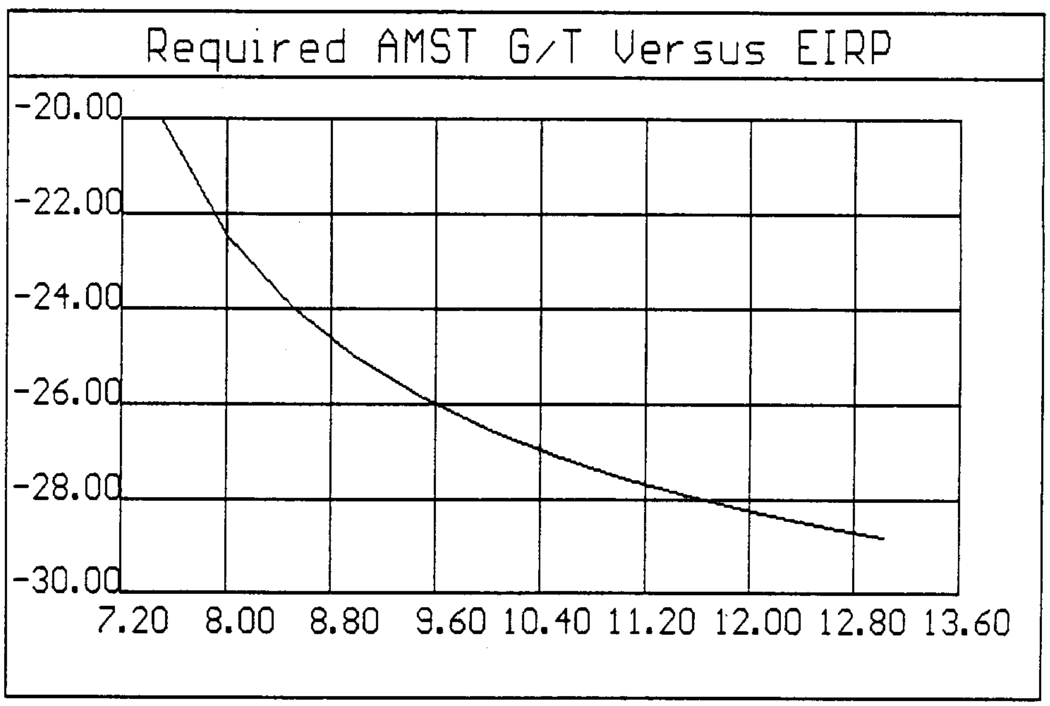

Figure A2.6 (G/T), dB Versus $EIRP_u$, dBW
UFO @ 5°, 5k Trans., 2400 bps

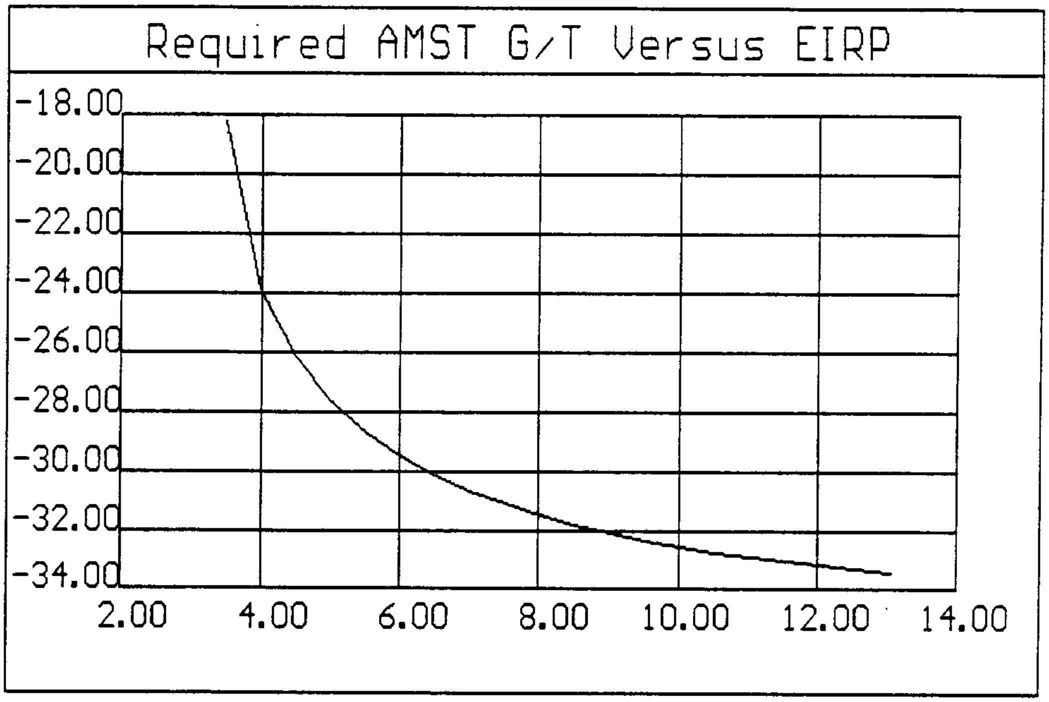

Figure A2.7 (G/T), dB Versus $EIRP_u$, dBW
UFO @ 30°, 5k Trans., 2400 bps

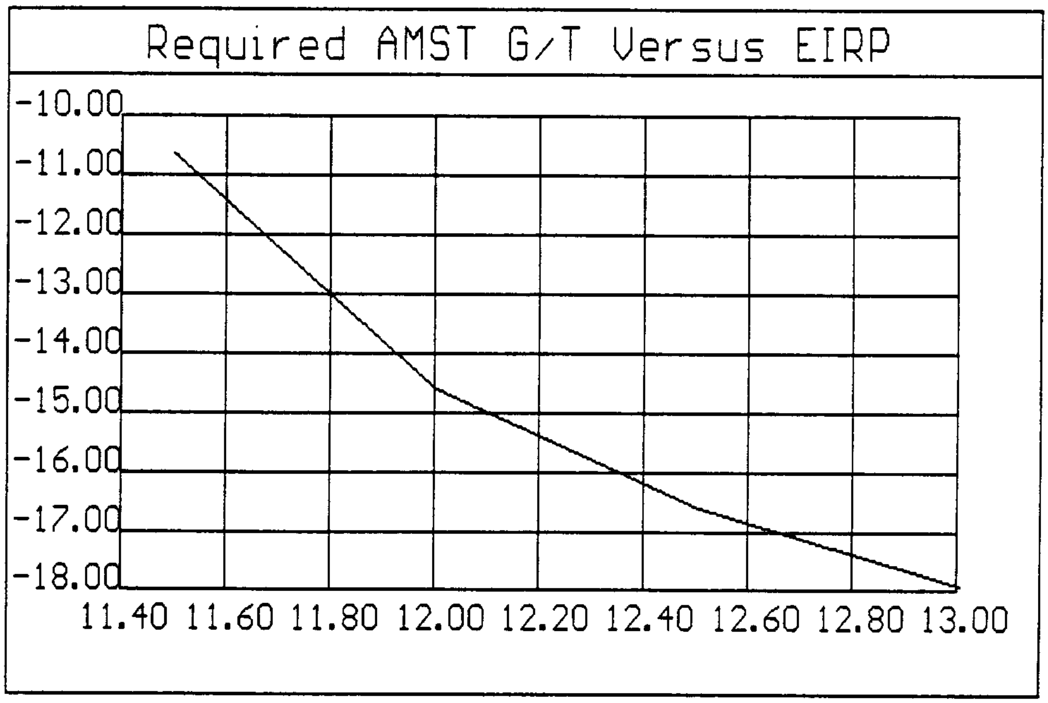

Figure A2.8 (G/T), dB Versus $EIRP_u$, dBW
LEASAT @ 5°, 5k Trans., 4800 bps

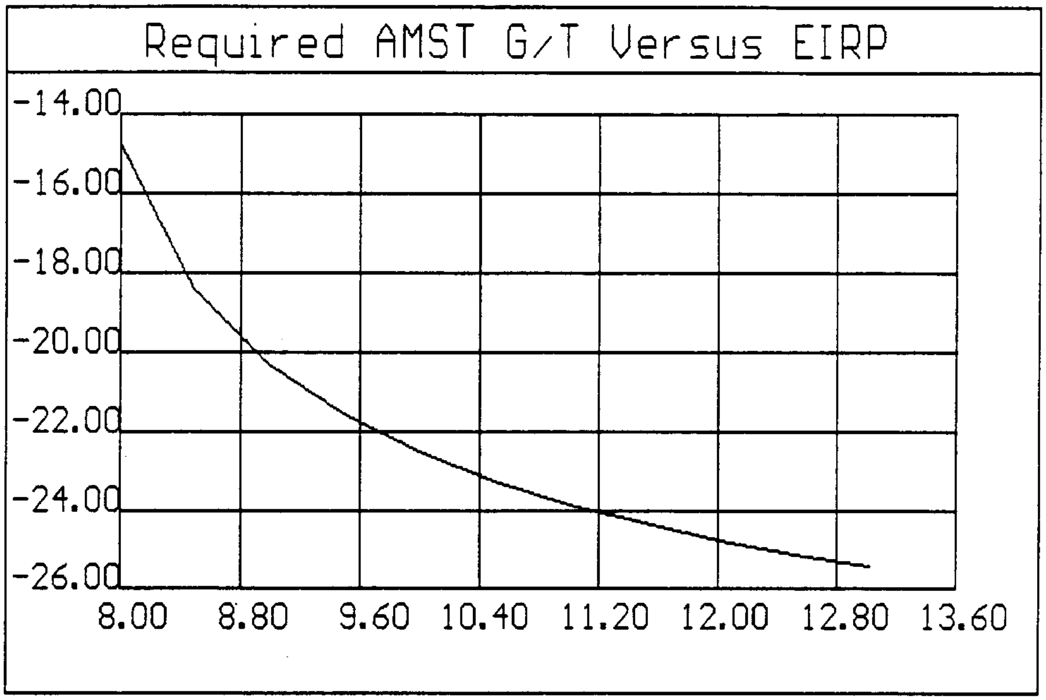

Figure A2.9 (G/T), dB Versus $EIRP_u$, dBW
LEASAT @ 30°, 5k Trans., 4800 bps

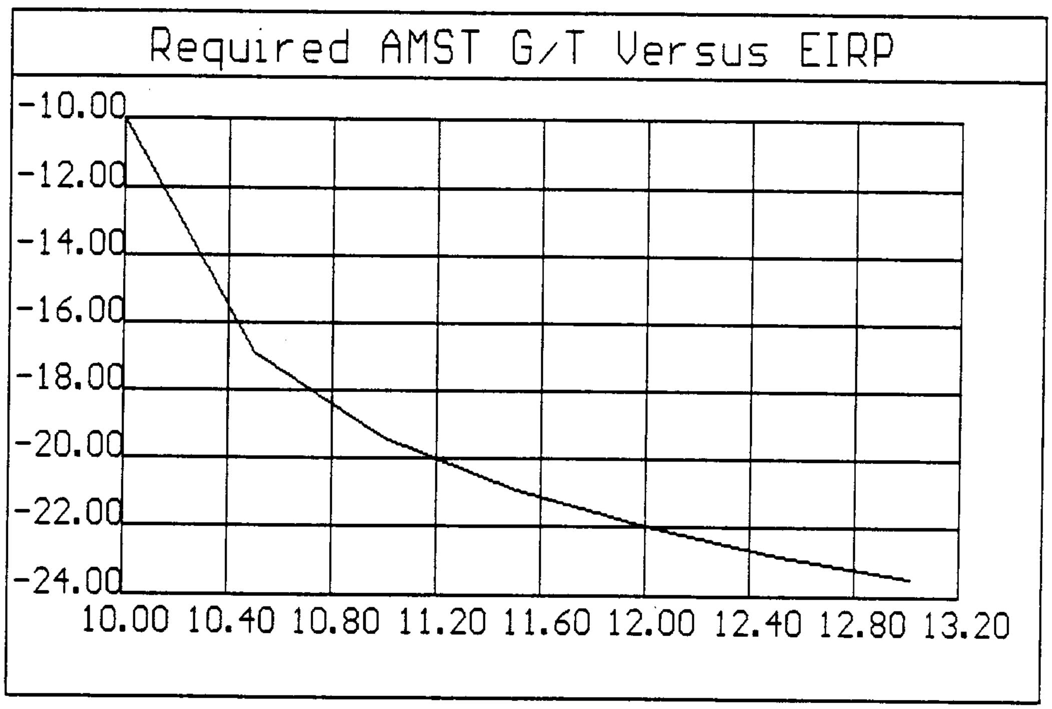

Figure A2.10 (G/T), dB Versus $EIRP_u$, dBW
UFO @ 5°, 5k Trans., 4800 bps

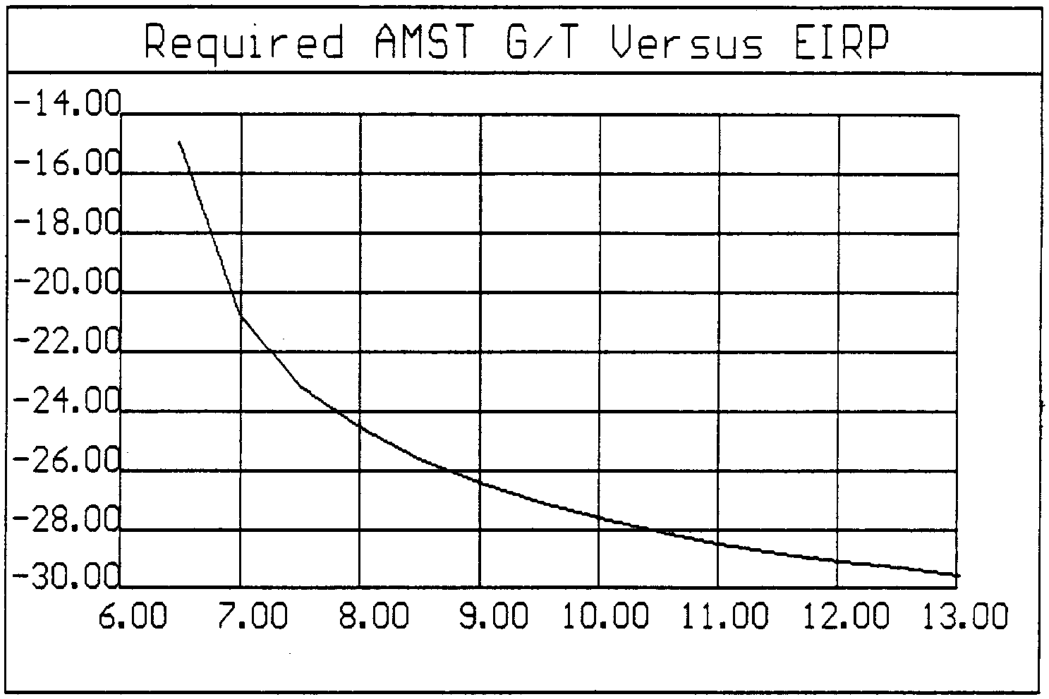

Figure A2.11 (G/T), dB Versus $EIRP_u$, dBW
UFO @ 30°, 5k Trans., 4800 bps

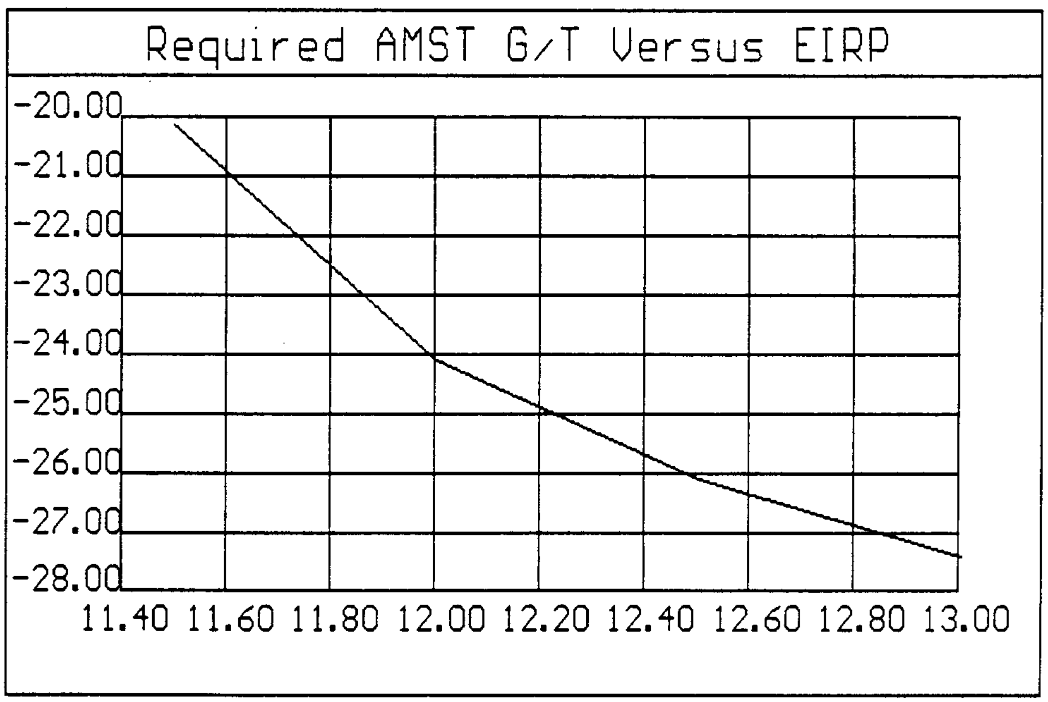

Figure A2.12 (G/T), dB Versus $EIRP_u$, dBW
LEASAT @ 5°, 25k Trans., 4800 bps

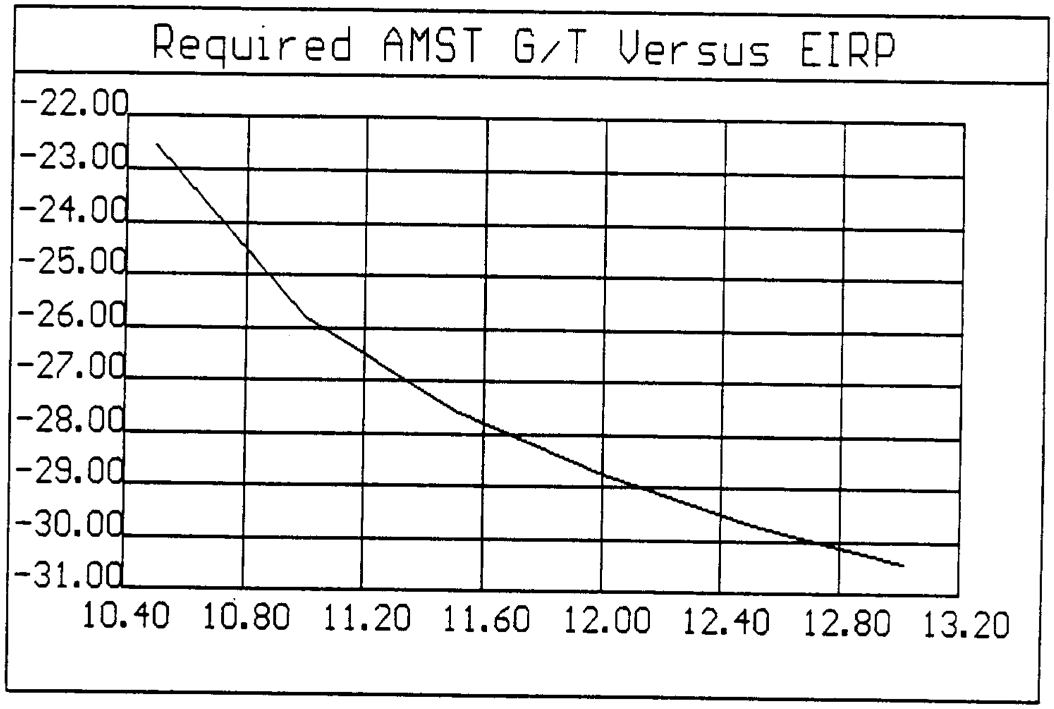

Figure A2.13 (G/T), dB Versus $EIRP_u$, dBW
LEASAT @ 5°, 25k Trans., 4800 bps

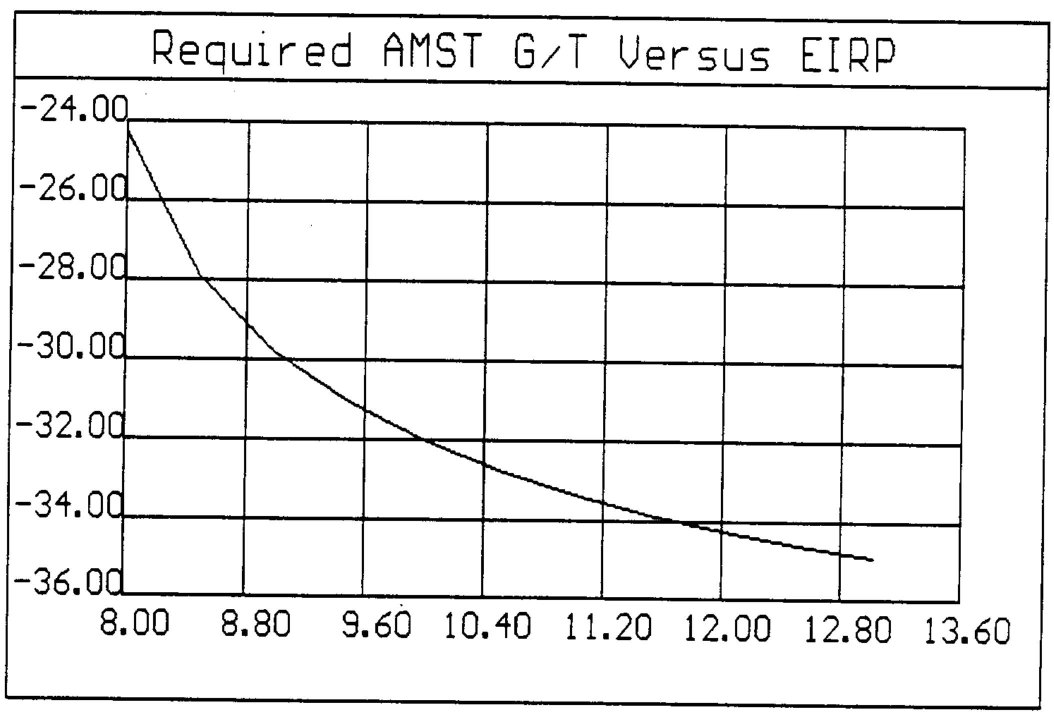

Figure A2.14 (G/T), dB Versus $EIRP_u$, dBW
LEASAT @ 30°, 25k Trans., 4800 bps

Appendix II References

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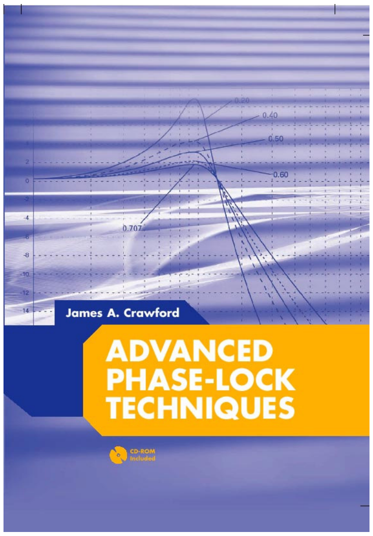

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Chapter	Brief Description	*Pages*
1	*Phase-Locked Systems—A High-Level Perspective* An expansive, multi-disciplined view of the PLL, its history, and its wide application.	26
2	*Design Notes* A compilation of design notes and formulas that are developed in details separately in the text. Includes an exhaustive list of closed-form results for the classic type-2 PLL, many of which have not been published before.	44
3	*Fundamental Limits* A detailed discussion of the many fundamental limits that PLL designers may have to be attentive to or else never achieve their lofty performance objectives, e.g., Paley-Wiener Criterion, Poisson Sum, Time-Bandwidth Product.	38
4	*Noise in PLL-Based Systems* An extensive look at noise, its sources, and its modeling in PLL systems. Includes special attention to $1/f$ noise, and the creation of custom noise sources that exhibit specific power spectral densities.	66
5	*System Performance* A detailed look at phase noise and clock-jitter, and their effects on system performance. Attention given to transmitters, receivers, and specific signaling waveforms like OFDM, M-QAM, M-PSK. Relationships between EVM and image suppression are presented for the first time. The effect of phase noise on channel capacity and channel cutoff rate are also developed.	48
6	*Fundamental Concepts for Continuous-Time Systems* A thorough examination of the classical continuous-time PLL up through 4^{th}-order. The powerful Haggai constant phase-margin architecture is presented along with the type-3 PLL. Pseudo-continuous PLL systems (the most common PLL type in use today) are examined rigorously. Transient response calculation methods, 9 in total, are discussed in detail.	71
7	*Fundamental Concepts for Sampled-Data Control Systems* A thorough discussion of sampling effects in continuous-time systems is developed in terms of the z-transform, and closed-form results given through 4^{th}-order.	32
8	*Fractional-N Frequency Synthesizers* A historic look at the fractional-N frequency synthesis method based on the U.S. patent record is first presented, followed by a thorough treatment of the concept based on Δ-Σ methods.	54
9	*Oscillators* An exhaustive look at oscillator fundamentals, configurations, and their use in PLL systems.	62
10	*Clock and Data Recovery* Bit synchronization and clock recovery are developed in rigorous terms and compared to the theoretical performance attainable as dictated by the Cramer-Rao bound.	52