Analysis of Utilization Bandwidth and Power Transponder Extended C-Band on The Satellite Telkom 3S VSAT SCPC

Shinta Romadhona¹*, Intan Rizqiyan Nur Faizah², Imam MP Budi³
¹,²,³ Institut Teknologi Telkom Purwokerto
D.I Panjaian Street No.128 Purwokerto, Jawa Tengah, Indonesia
*Corresponding email: shinta@ittelkom-pwt.ac.id

Received 05 April 2020, Revised 21 April 2020, Accepted 25 April 2020

Abstract - On satellite communication systems, bandwidth and power are limited and expensive resources. Optimization of bandwidth and power utilization in Telkom 3S Satellite could be achieved if the ratio value of the percentage of bandwidth and power is 1:1. The optimization conditions are influenced by the calculation of the link budget, the use of appropriate modulation and FEC settings. QPSK and 8-PSK modulation techniques with FEC used are 3/4, 7/8, and 9/10 with a 9 m Hub antenna and VSAT SCPC with a diameter of 2.4 m with roll-off factor 0.5 and data rate of 1024 kbps. Based on the results of this research, the lower the modulation technique used, the lower the ratio of bandwidth and power. The most optimal FEC value to be used was 8-PSK modulation at FEC 93/100 with the resulting percentage was 97.25%, where the total carrier bandwidth generated was 93.415, and the amount of carrier power was 96.05, whereas was QPSK with FEC 3/4 by which producing a percentage of 35% which is in the limited power category. Thus, the most appropriate modulation used on the Telkom 3S Satellite is the 8-PSK modulation with an FEC of 93/100.

Keywords – QPSK, 8-PSK, FEC, VSAT SCPC, Roll-off factor 0.5, data rate 1024 kbps.

I. INTRODUCTION

A satellite communication system has a large capacity and has a high speed, and could reach into remote areas. In the operation of the satellite, bandwidth and power are the main parameters. There are two conditions for a transponder capacity, which could be bandwidth limited or power-limited. The best condition is when it is in optimum condition, where the percentage of bandwidth usage is equivalent to the percentage of power-limited usage [1].

Conditions for the availability of bandwidth and power are always different in percentage even though to achieve the optimum value, the value of bandwidth-limited must be the same as power-limited. To achieve the optimum value in a satellite transponder, parameters should be considered, such as choosing the right modulation technique, end-to-end link budget calculation. Bandwidth and power availability are very limited [2]. Then it is necessary to choose the right modulation technique, such as QPSK modulation technique, or 8-PSK modulation technique that will be used for the most appropriate comparison between the modulation techniques. Based on the economic value of PT. Aplikanusa Lintasarta the price of bandwidth and power is relatively expensive, it is necessary to calculate the end-to-end budget link calculation, and perform Error-Correcting Scheme (Forward Error Correction or FEC) measurements to optimize the use of bandwidth and power on the transponder, analyzing the effect of QPSK modulation techniques and 8-PSK in terms of bandwidth and satellite power, analyzing the influence of SCPC (Single Channel Per Carrier) for optimizing bandwidth and satellite power. The company's costs could be reduced to a minimum so that bandwidth and power usage could be used optimally.

This research examines the effect of modulation changes on bandwidth and link quality in satellite communication systems. The choice of modulation parameters causes changes in bandwidth requirements adjusted to the modulation technique used in this research using three modulation techniques including QPSK, 8-PSK, and 16-APSK which produce FEC
values of 3/4 and produce data rate values of 8 Mbps. 16-APSK produces the most bandwidth values small, and more efficient with a bandwidth difference of up to 3886.18 KHz. In contrast, the use of 8-PSK modulation has a difference of 2590.83 KHz [3].

In the other examination, the performance of the modem used by PT. Metrasat on the Chinasat-11 satellite is measured. To find out the quality of PT. Metrasat, it is necessary to calculate the link budget first. The lower the modulation level used, the wider the bandwidth value [2].

Another research examines the feasibility analysis of modulation on Telkom-1 satellites in terms of bandwidth and power. The result is that the most appropriate modulation used on the Telkom-1 satellite for IDR services is the QPSK modulation technique that uses 3-meter antenna diameters, and the worst modulation used on the Telkom-1 satellite is the 16QAM modulation technique. The transponder capacity will be even greater when using a high-order modulation, this is viewed in terms of bandwidth, whereas if viewed in terms of power, the higher the modulation order, the smaller the transponder capacity [4].

Based on this background, the author conducts the analysis of bandwidth and power by comparison between QPSK and 8-PSK modulation techniques, with the calculation of an end-to-end budget link to get the optimum value of satellite transponders with the lowest possible cost on VSAT-SCPC conducted at Indosat Jatiluhur Earth Station, Purwakarta.

II. RESEARCH METHOD

This research analyzes the use of C-band bandwidth and power transponder on a particular satellite in order to obtain the value of satellite optimization using QPSK, 8-PSK modulation techniques, and simulations to show the signal results of the comparison between the two modulations. The simulation model implemented in this research uses the SatMaster program.

A. Bandwidth and Power

Bandwidth or width of a frequency band is a roll-off factor of the number of bits in a single symbol that is calculated into the speed of information (FEC). In calculating the bandwidth, there is a digital encoding that serves to detect and correct errors and correct BER, which will show errors in digital transmissions. The coding uses FEC coding. FEC will increase the number of bits sent so that the bit rate increases but does not extend the transmission time [4]

\[ BW_{occ} = \frac{DR}{Mod} \times (1 + Roll-off \text{ factor}) \]  

\[ Symbol\ Rate = \frac{DR}{Mod} \]  

Information:

- DR : Data Rate (kbps)
- FEC : Forward Error Correction [3]
- Mod : Modulation
- \( \alpha \) : Roll-off factor \((0 \leq \alpha \leq 1)\) [4]

In terms of bandwidth, it could be seen the number of carriers in one transponder that could be formulated as follows [4]

\[ \text{numberofcarrier} = \frac{BW_{occ}}{BW_{ALL}} \]  

Meanwhile, the power transponder operation can be calculated as follows (4),

\[ \text{Power}_{Sat\text{.Saturation}} = \text{EIRP}_{Sat\text{.Saturation}} - \text{OBO} \]  

In terms of power, the number of carriers in one transponder can be formulated by (5),

\[ \text{numberofcarrier} = \frac{EIRP_{Sat\text{.Saturation}} - \text{OBO}}{\text{Powerocc}} \]  

\[ \text{comparisonofBWAPWR} = \frac{\text{numberofcarrierbandwidth}}{\text{numberofcarrierpower}} \times 100\% \]  

Information:

- BWocc : Bandwidth Occupied
- OBO : Output Backoff
- BWXPNDR : Bandwidth Transponder
- EIRPSat.Saturation : Effective Isotropic Radiated Power Satellite saturation [4]

B. QPSK Modulation Technique

In QPSK modulation or Quadrature Phase Shift Keying, the carrier signal presents four phase states to express four symbols, with one symbol consisting of two bits namely "00", "01", "10", and "11". In QPSK modulation the value of m = 2, which means \( 2^m = 4 \) [5]

C. 8-PSK Modulation Technique

The 8-PSK or Eight-Phase State Phase Shift Keying modulation technique, undergoes a phase change of 45° derived from the value of \( m = 3 \), \( 2^m = 3^2 = 8 \) and then \( \frac{360°}{8} = 45° \) so that the phase size produced by 8-PSK is 45°. The information bitrate is 3 times the speed of the symbol, in 8-PSK modulation it presents eight phases for eight symbols, with one symbol consisting of 3 bits, namely "000", "001", "011", "010", "110", "111", "101" and "100" [4]

D. Link Budget Calculation

a) Effective Isotropic Radiated Power (EIRP)

The EIRP will show the effective power emitted from an antenna that has its gain. If there is attenuation on the transmission line or there is a loss of feeder, then the EIRP value will be reduced [3].

\[ EIRP = \text{Pout HPA (dBw)} + G \text{ antenna (dB)} - \text{IFL loss (dB)} \]  

EIRP prices could be reduced and enlarged by:

- Shortening or extending IFL value
- Reduce or enlarge the HPA output
- Shortening or extending IFL [6]
b) System Noise Temperature (T)
The noise system T is a function of the noise temperature antenna. It has influenced by meteorological conditions and rain attenuation due to rising temperatures in the atmosphere. Meanwhile, the noise temperature in the antenna depends on the elevation angle. G / T is defined as the minimum value of the elevation angle and is in clean atmospheric conditions. At the earth station, the cleaner the G / T value will be better [7].

c) Gain to Noise Temperature (G/T)
The G/T value is usually used to indicate the performance relation between the earth station antenna and the LNA or Low Noise Amplifier to determine the quality of the downlink signal coming from the satellite. Gain to Noise Temperature or G/T, has two parameters, namely the G parameter and the T parameter. The G parameter itself is the receiver antenna gain based on the LNA (Low Noise Amplifier) input value, while the T parameter is the system noise temperature at the earth station based on the LNA (Low Noise Amplifier) [8].

d) Elevation Angle
Elevation angle is the angle formed from the local horizon plane with LOS (Line of Sight) of the Earth Station towards the satellite direction with the zero point located in the local horizon plane with the direction of rotation upward [9].

\[ E = \tan^{-1} \]  

(8)

Information:
\[ \cos l : \cos \text{station latitude value} \]
\[ \cos L : \text{earth station's longitude reduction value} \]
with the longitude of the satellite[6]

e) Azimuth Angle
The angle between the north direction line and the line towards the satellite projection point in the local horizon plane of the earth station is the azimuth angle. To calculate the satellite elevation angle, use the following (9)[9].

\[ A_z = \tan^{-1} \frac{b}{c} \]  

(9)

\[ b : \text{longitude SB-longitude satellite } \]
\[ c : \text{latitude Earth Station} [7] \]

E. Telkom 3S Satellite
Satellite communication has an extensive reach that could reach remote areas. Telkom 3S Satellite is a satellite owned by Telkom Indonesia in GEO (Geostationary Earth Orbit) orbit. Telkom 3S satellite has a circular path with the same axis of rotation as the earth and placed in a position above the equator. Telkom 3S Satellite Coverage is the territory of Indonesia, Southeast Asia, and parts of East Asia. Telkom satellite launch on February 15, 2017, at 04.39 WIB at Guiana Space Center, Kourou, French Guiana, by using the Ariane 5 ECA VA235 rocket owned by the satellite launch company, Arianespace Europe. Telkom 3S satellite is in an orbital position 118° with a satellite age of 17 years and with a mass of 3550 kg [10].

F. VSAT SCPC (Single Channel Per Carrier)
SCPC or Single Channel Per Carrier is a form of transmission of satellite communication where the transmission process is carried out on a single carrier that has been predetermined. In SCPC, you can uplink the same transponder from many locations[11].

In SCPC, satellite communication can be operated analog or digital, if analog, then using FM (Frequency Modulation). Meanwhile, it can also be digitally using PSK modulation or Phase Shift Keying [12].

SCPC has the principle of using access based on frequency division [13]. To carry out the processing of signal channel modulation a separate RF carrier, which is then transmitted to FDMA Transponder. SCPC has a carrier that is divided into two operating modes as follows:

1. Pre- Assigned FDMA, the frequency slots are pre-assigned to the Earth stations. The slot allocations are pre-determined and do not offer flexibility. Hence, some slots may be facing the problem of over-traffic, while other slots are sitting idle

2. Demand Assigned FDMA the transponder frequency is subdivided into a number of channels and the Earth station is assigned a channel depending upon its request to the control station. [14].

G. Power-Limited and Bandwidth-Limited
Fig.1 is a graph of the optimization of bandwidth and power values to specify whether the transmission values in the modulation and the FEC used are included in the bandwidth- or power-limited. Bandwidth and power usage will be specified for achieving optimization if the ratio between the two is 1:1. Power-limited is a condition in which satellite transmission uses too much power, so it does not reach the optimization value.

Fig.2 represents a power-limited condition where the condition exceeds the 1:1 ratio limit. This could be seen in the pink graph above the ratio of power-limited and bandwidth-limited, while the bandwidth-limited condition could be seen in Fig. 3.

The following is a power-limited condition graph:
Analysis of Utilization Bandwidth and Power Transponder Extended C-Band on The Satellite Telkom 3S VSAT SCPC

It is categorized bandwidth-limited if the value of the ratio between power and bandwidth is not 1:1; this means the bandwidth used exceeding what it should be. Bandwidth limited values could be seen on the pink graph to the side.

H. SatMaster Setting of Telkom 3S Satellite

In this research, link budget calculation is used with formulas and SatMaster software in Table 1. The purposes of using the SatMaster software are to get the accuracy of the results of using link budget calculation with formulas, and then compare the result of the formulas with SatMaster software. If it’s the same, it is precise.

Table 1. SatMaster Setting of Telkom 3S Satellite

| No. | Parameter               | Calculation Result | SatMaster Result | Deviation (%) |
|-----|-------------------------|--------------------|-----------------|---------------|
| 1   | G/T                     | 2 dB/K             | 2 dB/K          | 0             |
| 2   | Elevation               | 74.986°            | 75.36°          | 0.496         |
| 3   | Azimuth                 | 59.485°            | 59.83°          | 0.576         |
| 4   | Gain antenna uplink     | 54.428 dBi         | 53.82 dBi       | 1.117         |
| 5   | Gain antenna downlink   | 37.403 dBi         | 36.80 dBi       | 1.612         |
| 6   | Transmit EIRP           | 68.0388 dBW        | 68.73 dBW       | 1.005         |
| 7   | Free Space Loss Uplink  | 199.714 dB         | 199.76 dB       | 0.046         |
| 8   | System Margin           | 2 dB               | 2 dB            | 0             |
| 9   | Symbol Rate             | 367.025 kSps       | 0.3670 Mbaud    | 0.0068        |
| 10  | Bandwidth Occupied      | 385.376 kHz/carrier| 0.3854 MHz      | 0.0062        |
| 11  | Percentage transponder bandwidth used | 1 % | 1.39 % | 28.057 |

Limited by: power equivalent bandwidth usage

III. RESULT

Utilization of bandwidth and power analysis is performed using two modulation techniques, namely QPSK, and 8-PSK with FEC values of 3/4, 7/8, and 93/100 at a data rate of 1.024 Mbps. Satellite transmission is performed using a 9 m diameter hub antenna and a 2.4 m diameter VSPC SCPC loopback using a Teledyne Paradise Datacom Satellite Modem. Based on the results of the Telkom 3S satellite transmission, the carrier signal is obtained using QPSK modulation on the FEC 3/4 as shown in Fig. 4.

The transmission of the satellite is also using the 8-PSK modulation with FEC of 93/100. The carrier signal is shown in Fig. 5.

The following of Table 2 is the result of link budget calculation in terms of bandwidth occupied and some carrier bandwidth percentage.

Meanwhile, the number of carrier power could be seen on Table 3.
IV. DISCUSSION

In Fig. 4, it could be seen that the shape of the more significant carrier signal represents the carrier signal generated by the 9 m hub antenna. In comparison, the one next to it was representation of the 2.4 m diameter antenna. The bandwidth value obtained in the QPSK modulation with FEC of 3/4 is 683.636 kHz on the 9 m antennae, while the 2.4 m antenna is 712.727 kHz. Meanwhile, occupied bandwidth, which has been calculated using QPSK, FEC 3/4, produces a value of 716.8 kHz. The bandwidth value is obtained from the calculation of the formula and satellite transmission is almost the same. The C/N value obtained by 9 m diameter antenna using QPSK modulation FEC of 3/4 is 11.84 dB, which is included in the good link category. Whereas, for 2.4 m antennas get a C/N value of 7.35 dB while the results of the calculation produced the value of \( \frac{C}{N} \) on the hub is 15.34 dB and \( \frac{C}{N} \) on the remote is 13.35 dB.

The bandwidth value obtained in Fig. 5 for the 8-PSK modulation with FEC of 93/100 is 398.181 kHz on the 9 m antennae, while in the 2.4 m antennae, the value is 381.818 kHz. The value generated from the results of satellite transmission is 381.818 kHz. In comparison, the results of the calculation of the formula are 385.376 kHz, so the bandwidth values obtained from the calculation results of the formula and satellite transmission are almost the same then the exact value for the formula calculation. The power obtained at 9 m antenna is -90.03 dBm, and at 2.4 m antenna is -90.05 dBm. The C/N value obtained at the 9 m antenna is 13.41 dB, which is included in the good link category. Meanwhile, for 2.4 m antennas gain a C/N value of 8.86 dB. The value of C/N is useful to calculate \( \frac{C}{N} \) and it produces the result of \( \frac{C}{N} \) on the hub is 16.91 dB and \( \frac{C}{N} \) on the remote is 14.86 dB.

The following is the comparison between bandwidth and power on 8-PSK modulation with FEC of 93.

- Number of carrier \( pwr_{\text{hub}} \)
  \[ \text{Number of carrier power}_{\text{hub}} = (EIRP_{\text{Sat.Saturation}} - OBO) + \text{PowerOccupied} \]
  \[ = (42 - 6) + 60.03 \]
  \[ = 96.03 \text{ carrier} \]

- **Summary carrier power**
  \[ \text{Summary carrier power}_{\text{hub}} = \frac{\text{Summary carrier bandwidth}}{100\%} \]
  \[ = \frac{93.415}{100\%} \]
  \[ = 96.03 \]

- **Comparison between bandwidth**
  \[ \text{Comparison between bandwidth} = \frac{\text{Summary carrier bandwidth}}{100\%} \]
  \[ = \frac{93.415}{100\%} \]
  \[ = 96.05 \% \]
  \[ = 97.25 \% \]

QPSK modulation with FEC 3/4 on the hub obtained 52.2% results with the number of carrier Bandwidth of 50.223 carriers, and the number of carrier power of 96.09 carriers, and the remote obtained a percentage of 52.7%. Thus, the worst modulation to use is QPSK with FEC of 3/4. Whereas the most optimal modulation to be used is 8-PSK FEC of 93/100 with the results on the hub of 97.23% with a total carrier bandwidth of 93.415 carriers, and a total carrier power of 96.03 carriers, and on the remote, the results are 97.25% where both achieve optimization conditions and reach a ratio of 1:1 for bandwidth and power. Following is the calculation of the ratio of bandwidth and power in QPSK modulation with FEC of ¾.

The value of power using the QPSK with FEC of ¾.

- Power receive on antenna diameter of 9 m is 90.09 dBm = 90.09 - 30 = 60.09 dBW
• Power receive on antenna diameter of 2.4 m is 89.18 dBm = 89.18 - 30 = 59.18 dBW.

• Number of carrier power \(P_{\text{carrier}}\):
  \[
  P_{\text{carrier}} = \frac{\text{EIRP}}{\text{Sat.Saturation}} + \text{PowerOccupied}
  \]

  \(= (42.6) + 60.09 = 96.09\) carrier

• Summary carrier power \(P_{\text{hub}}\):
  \[
  P_{\text{hub}} = \frac{\text{EIRP}}{\text{Sat.Saturation}} + \text{PowerOccupied}
  \]

  \(= (42.6) + 59.18 = 95.18\) carrier

So,

- comparison between bandwidth \(A\) and power \(P_{\text{hub}}\):
  \[
  P_{\text{hub}} = \frac{\text{Summary carrier power}}{\text{Summary carrier bandwidth}} \times 100\%
  \]

  \(= \frac{95.18}{50.223} \times 100\% = 52.2\%
  
  \text{comparsion bandwidth \(A\) and power \(P_{\text{hub}}\)}:

  \[
  P_{\text{hub}} = \frac{\text{Summary carrier power}}{\text{Summary carrier bandwidth}} \times 100\%
  \]

  \(= \frac{50.223}{95.18} \times 100\% = 52.7\%\)

In the calculation of the transmission that is done, produce a value that could be categorized into power-limited, namely QPSK modulation with FEC ¾. Meanwhile, the optimal modulation is 8-PSK with FEC of 93/100.

In VSAT SCPC (Single Channel Per Carrier), each PAMA type is modulated by a single voice or from low to medium bit rate data. In voice transmission, the carrier signal is voice allocation and only uses 40% power or saves 60% power on satellite transponders. However, based on the results of direct satellite calculation and transmission, it is obtained that the excess power usage in the QPSK modulation with FEC is ¾ where the number of carrier power that is obtained, in Table 3, the hub is 96.09 carrier, which is greater than the number of carrier bandwidth produced by 50.223 carriers and on the remote. The number of carrier power is 95.18 carrier in Table 2, while the number of carrier bandwidth is 50.223 carriers. In this research also obtained optimal condition namely using 8-PSK modulation with FEC of 93/100 and obtained a ratio of 1:1 with a total carrier power of 96.03 carriers and a total carrier bandwidth of 93.415 carriers at the hub, and the number of carrier power amounted to 96.05 carriers, and the number of carrier bandwidth is 93.415 carrier.

V. CONCLUSION

Based on the obtained results for which subject to research objective, it can be concluded that calculation of the link budget is done by using the formulas of the calculation, which is then compared using the SatMaster software, the best modulation is used for 8-PSK with FEC of 93/100 the percentage of bandwidth using a formula is 1%, and for SatMaster is 1, 39%. Meanwhile, the percentage of power generated is 2.17% either in formula calculation or with SatMaster software. FEC settings are performed using the Teledyne Paradise Datacom Satellite Modem. Based on the analysis of the link budget by changing the FEC parameters equal to 93/100 on the 8-PSK modulation, the percentage of power and bandwidth is 97.23% for the hub, while for the remote is 97.25%.

The lower the modulation used, the lower the percentage value of the bandwidth and power ratio by using the same FEC value. In this study, the best modulation to be used was 8-PSK at FEC of 93/100, with a percentage of 97.23% at the hub, while at the remote at 97.25%. Meanwhile, the worst to use is QPSK with FEC of ¾ with a percentage of 52.2% on the hub, while on the remote of 52.7%. Based on the calculation of the percentage of bandwidth and power, it is concluded that the transponder has limited power, then the maximum number of carriers that can be occupied in one transponder is 96.03 carriers. Using VSAT SCPC could save power transponder usage by about 60% if the selection of modulation and FEC is correct. If it is not right, it will cause an overload of power so that the transponder could be saturated.

REFERENCES

[1] V. Rosana, “Analisis Kinerja Sistem Komunikasi Satelit Telkom-2,” Telkom University Bandung, pp. 1-9, 2007.

[2] A. A. Situmeang, “Analisa Performasi Sistem Komunikasi Satelit Chinasat-11 Pada Tingkat Modulasi BPSK, QPSK, 8PSK, dan 16QAM,” Sekolah Tinggi Teknologi Purwokerto, Purwokerto, 2017.

[3] D. Prativi and M. Gafar, “Pengaruh Perubahan Modulasi Terhadap Bandwidth Dan Kualitas Link Sistem Komunikasi Satelit,” Sainstech, vol. 25, no. 2, pp. 47–53, 2015.

[4] S. Ariyanti and B. A. Purwanto, “Analisis kinerja penggunaan modulasi QPSK, 8PSK, 16QAM pada satelit Telkom-1,” Bud. Pos dan Telekomun., vol. 11, no. 1, p. 45, 2015.

[5] L. J. Ippolito Jr, Satellite Communications Systems Engineering, Second ed. Washington DC, USA: John Wiley & Son Ltd, 2017.

[6] I. MPB and W. Pamangkas, Sistem Komunikasi Satelit. Yogyakarta: CV. Andi OFFSET, 2014.

[7] G. Maral and M. Bousquet, Satellite Communications Systems, Fifth. Singapore by Markono Print Media Pte Ltd: J. W. &. Sons, 2009.

[8] T. T. Ha, Digital Satellite Communications, Second Edi. Singapore: McGraw-Hill, 1990.
[9] O. A. Basuki, E. B. P, and S. N. Sari, “Analisis Link Budget dengan Perbedaan Sudut Azimuth dan Sudut Elevasi pada Proses Pointing Menggunakan Two Line Elements dan Perhitungan Matematis Pada Satelit Telkom-1 dan Telkom-2,” *J. ECCIS*, vol. 10, no. 1, pp. 33–38, 2016.

[10] Telkom Indonesia, “Satelit Telkom 3S,” *Telkom Indonesia*, 2017. [Online]. Available: http://www.satelittelkom3s.com.

[11] Faq-Tech, “SCPC (Single Channel Per Carrier),” *Faq-Tech*. [Online]. Available: http://www.tech-faq.com/scpc.html.

[12] *Handbook Satellite Communications*. Geneva: International Radio Consultive Commite, 1988.

[13] D. Erianto, D. Arseno, and G. Jonathan, “Perancangan Dan Analisis Komunikasi Rural Menggunakan Scpc( Single Channel Per Carrier ) Secara Power Dan Bandwidth Menggunakan Android,” Telkom University Bandung, 2012.

[14] A. K. Maini and V. Agrawal, *Satellite Technology*. Thomson Digital, Noida, India: John Wiley & Son Ltd, 2011.

[15] P. Jakobsson, *Link Budget Course*. Swedish Satellite System.