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Margins Roll in Determination of HPA Sizing for Different Types of Carriers

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Abstract

A satellite transponder having finite resources in terms of bandwidth and power, leasing costs are determined by bandwidth and power used. For optimal utilization, a satellite circuit should be designed to use similar share of transponder bandwidth and transponder power. The main objectives are summarized in determining the significant differ when single and multicarriers, in the regardless of the number of carrier are used. This paper ensuring why the transmission budget take this single in consideration and don't care with the specific carrier number in the multicarrier. This was achieved by studies the effect of margins (up and down) in the HPA sizing and EIRPs. This paper detected that, the precise value of HPA size that required to upgrade the link capacity represent in increasing the carrier number, in order to upgrade the link from single carrier to 7 carriers, this required to increasing 47.943 dBW of HPA sizing and just 0.326 dBW required to upgrade the link from 2 to 7 carriers. When margin increased to 18 dB the required 46.95 dBW and 0.331dB respectively, also the precise value for requiring EIRP, the study reveal that, the Margin has significant effect in the EIRP that radiated from the E/S and not effected In that radiated from a satellite, on the other hand This EIRP has not any effect in the carrier numbering. Finally, mathematical equations and plotting a nearest curve are revealed, explaining the Relation between carriers and required HPA sizing at different margin.

Keywords: *HPA, Antenna, Carrier and Power Density.*

Introduction

A link budget analysis forms the cornerstone of the system design Link budgets are performed in order to analyse the critical factors in the transmission chain and to optimize the performance characteristics, such as transmission power, bit rate and so on, in order to ensure that a given target quality of service can be achieved.

Antenna

When calculating a satellite link budget, several factors including transmitted and received data rates, modulation, FEC, antenna sizes and geographic location within the satellite beam have to be taken into account. Typically, the satellite link budget results give the transmitted and received power to and from the satellite, the satellite link budget availability and the amount of satellite bandwidth required to operate the service.(1)

Doing the antenna pattern measurements

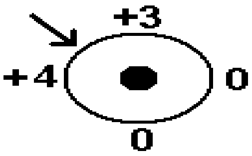
Drive the antenna left and watch the main beam level drop, go past the first null and first side-lobe peak and then stop maybe 5 dB down beyond the first sidelobe peak. Write down the azimuth and elevation encoder positions. This is the azimuth start position. Then start the drive motors to the right and press single sweep start. Wait till you have the full pattern and then stop the azimuth motor. If all goes well you will have pattern like that below:

If you have a very big dish the satellite has probably moved by now and main beam reading will be low. Don't worry about this, you can't miss the first side lobe ring and those measurements are good. Write 0 dB against the lower level side-lobe and the relative value against the higher level sidelobe i.e. + 4 dB. Note that the +4 dB sidelobe came first and is therefore on the leading side of the dish main beam, ie. On the right hand side, looking towards the satellite.

Now drive the antenna back to the satellite and then go down in elevation to about -5 dB beyond the upper first sidelobe ring. Write down the azimuth and elevation encoder positions. This is the elevation start position. Drive the antenna upwards and plot the elevation cut. If all goes well you will have pattern like that below. Write 0 dB against the lower level sidelobe and the relative value against the higher level sidelobe e.g. + 3 dB

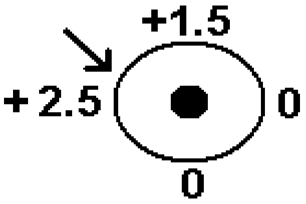
Note that the + 3 dB sidelobe came first so the high part is above the main beam, as you were moving the beam upwards in elevation (I hope).

Now consider just where the high part of the first sidelobe ring is. Go and stand in front of the dish, looking at it and note that the high part in the first sidelobe ring is in the top left area, where the arrow points.

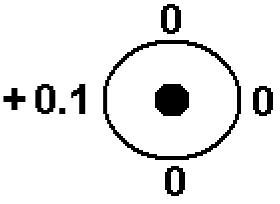


Assuming the dish is Cass grain, the task is to now push this high sidelobe down by tilting the sub-reflector so that the top left edge goes in towards the main reflector. Assuming 4 bolts make an adjustment of one full turn on two bolts so as to adjust both elevation and azimuth simultaneously.

The reason for choosing one full turn is that it is useful to learn what effect of one full turn is. Repeat the antenna pattern measurements and come up with a new diagram:



This tells us that 1 turn causes approx. 1.5 dB change in relative level. Also that the problem remains in the same general area of the sub-reflector. The top left needs to go in further. Now we can estimate the amount of movement needed. The top need to go a further 1.5 dB or 1 whole turn. The side need to go 2.5/1.5 turns or 1.66 turns or 1 turn and 4 flats. Note that 1 turn equals 6 flats of the nut.



This is near perfect and acceptable. (2)

Antenna Gain By convention, antenna gain figures used in a link budget is expressed in units of dBi; gain relative to a theoretical isotopic radiator. It is not uncommon for a manufacturer's datasheet to express antenna gain in units of dBd, gain relative to an actual dipole antenna. Relative to an isotropic radiator, a standard half wave vertical dipole antenna will exhibit an intrinsic gain of 2.15 dB in the horizontal. To calculate the gain in dBi of the transmitting antenna and the receiving antenna:

$$GTX = GRX = 3 + 2.15 \qquad (3)$$

For a circular aperture, the projected aperture is:

$$A = \pi d^2/4$$

And the effective aperture area Ae = A (for an ideal antenna)
Where:
d= antenna diameter
Taking into account losses and the no uniformity of the illumination law of the aperture, the effective area is in practice:

$$Ae = wA$$

$$Ae = £\,(d/2)2$$

Where £= antenna efficiency and < 1.

Efficiency is an important factor in antenna design. Special techniques are used to optimize the efficiency of Earth station antennas. Antenna efficiency is affected by:
a) The sub reflector and supporting structure blockage.
b) The main reflector rms surface deviation.
c) Illumination efficiency, which accounts for the non-uniformity of the illumination, phase distribution across the antenna surface, and power radiated in the side lobes.
d) The power that is radiated in the side lobes. (4)

Doubletalk Carrier-in-Carrier

It is complementary to all advances in modem technology, including advanced FEC and modulation techniques. As these technologies approach theoretical limits of power and bandwidth efficiencies, Doubletalk Carrier-in-Carrier utilizing advanced signal processing techniques provides a new dimension in bandwidth and power efficiency.
Doubletalk Carrier-in-Carrier allows satellite users to achieve spectral efficiencies (bps/Hz) that cannot be achieved with modulation and FEC alone. E.g., Doubletalk Carrier-in-Carrier when used with 16-QAM
Approaches the bandwidth efficiency of 256-QAM (8bps/Hz).
As Doubletalk Carrier-in-Carrier allows equivalent spectral efficiency using a lower order Modulation and/or FEC Code, it can simultaneously reduce CAPEX by allowing the use of a smaller BUC/HPA and/or
Antenna. (5)

Carrier and Power Density

Adjusting uplink earth stations transmit power (and possibly uplink earth station size) to obtain the exact figure you require at the satellite.

The figure you require may be derived from the power flux density to saturate the transponder (PDF/SAT). This figure is available from the uplink coverage map and the satellite transponder specification. For example the pfd/sat at beam Centre might be -83 dBW/m^2.The PFD/SAT on the -4dB contour would then be -79 dBW/m^2. The PDF/SAT figures can be altered by commanding changes in the gain setting of the satellite transponder, for example in the range -87 to -73 dBW/m^2 on the -4 dB contour.

The figures above refer to a whole transponder.
If transmitting an uplink signal with sufficient power to produce the PFD/SAT specified above you will saturate the transponder. This is applicable only by using one carrier in the transponder. In such a case the input and output back offs would both be zero.

For two carriers an input back off of 0.5 dB is suggested, with an output back off of about 1.5 dB due to the production of second order intermediation products.

In many cases 3 or more carriers are transmitted through the transponder and to avoid unacceptable intermediation interference levels it is necessary to operate the transponder backed off. Typical transponder operating points are:
Multi carrier: -6 dB input back off and -3.2 dB

output back off, intermod= 21 dB.
Multi carrier: -10 dB input back off and -4.5 dB output back off, intermod= 21 dB.
The satellite specification will provide a table or graph of input versus output values plus the carrier to intermediation ratio curve. Transponders with linearisers (e.g. above) allow operation nearer to saturation while keeping intermediation acceptable. Intermodulation worse than 15 dB starts to impact on the link budget, 18 to 21 dB is about optimum and 25 dB is too good and you are not making proper use of the downlink power available. The C/IM ratio changes at twice the rate of change of input back off.

Let us assume -10 dB input back off, for multi-carrier operation and carrier to intermediation = 21 dB.

So for beam edge operation, actual operating pfd is -79 -10 = -89 dBW/m^2. Remember this still applies to the whole transponder.

If the transponder bandwidth is 36 MHz and we want to operate in a 2 MHz wide slot the operating power flux density for this 2 MHz bandwidth is -89 -10 log(36/2) = -101.5 dBW/m^2.
You can't just put this in the link budget. You need to adjust the uplink earth station power (and possibly uplink earth station size) so that this required uplink pfd is achieved. Make the result equal to -101.5 dBW/m^2.

The satellite up-link beam pattern will have contours specifying both G/T and PFDsat. Read off the PFDsat for site and this will tell the PFD that need to produce for single carrier, full transponder operation. Asking the satellite operator to adjust the satellite transponder gain, and thus PFDsat, by setting attenuator switches on the satellite. This will allow trade off earth station costs, convenience and quality. For single carrier whole transponder operation PFD required = PFDsat

e.g. low gain for multi-carrier operation amongst large dishes, medium gain for single carrier operation and high gain for multi-carrier VSAT return links.

For multi-carrier operation, PFD required = PFDsat - transponder input back off - 10 x log (your carrier bandwidth / total transponder bandwidth)

Then, adjust the uplink EIRP till to get the required PFD at the satellite. Check that the uplink C/N is still reasonable. (6)

Motivation

Satellite technology can thus become a solution for some of the most complicated access problems, connecting cities across a large landmass, where copper or fiber would be cost prohibitive. Bringing broadband to the “last mile” of residences and businesses. Overcoming regulatory issues that make alternative carriers dependent on incumbents. Satellites also have a major role to play in designing, developing and expanding a network. With a satellite and Earth Stations, you can create a network on a permanent or interim basis much more rapidly than “laying cable.” An interim station will even let you test a market or provide emergency service prior to a major infrastructure investment. You can also rapidly scale and re-provision a satellite based network to meet increasing and changing needs.

Margin

To compensate for the residual noise, a small amount of additional link margin is required to maintain the desired BER. Margin requirements depend on the product, modulation and power ratios:
For example, the additional margin requirements for the CDM-625 Advanced Satellite Modem are as follows:

Modulation	Nominal Margin*
BPSK	0.3 dB
QPSK/OQPSK	0.3 dB
8-PSK	0.5 dB
8-QAM	0.4 dB

16-QAM	0.6 dB

* Equal power and equal symbol rate for the interfering carrier and the desired carrier, i.e. 0 dB PSD ratios. (1)

in planning an RF (radio frequency) telemetry link. One begins with the output power capacity of the transmitter and sums the system gains and losses to determine the level of power actually delivered to the receiver. To ensure a reliable link, the level of power available to the receiver should be in excess of that required for a minimum level of performance. An account of all the various gains and losses between the transmitter and the receiver is referred to as the link budget.

The level of received power in excess of that required for a specified minimum level of system performance is referred to as the fade margin. So called, because it provides a margin of safety in the event of a temporary attenuation or fading of the received signal power. The minimum required received power level used for the link budget can be totally arbitrary—owing to the designer's knowledge and experience—but is most often tied to the receiver's sensitivity. Simply put, the receiver's sensitivity specifies the minimum RF input power required to produce a useable output signal.(7)

High-Power Amplification

Today's wireless system requirements demand increasing performance from power amplifiers. (8)

Significant improvements continue to be achieved in high-power amplifier design; many claims are being made regarding the capabilities of each type of amplifier technology used in satellite uplink applications. Many companies will extol the virtues of the amplifier technology they offer, while playing down the strengths of technologies they do not offer. SSPA manufacturers historically have been the boldest practitioners of this strategy, often making lofty predictions about how their products will kill off TWTAs, KPAs, or both. For example, in 2011, one manufacturer excoriated those who "clung" to the "energy-draining tube technology of the past." In another advertisement from 2007, a manufacturer boldly announced a new line of "TWTA Killers," claiming reliability, efficiency and linearity advantages over TWTAs.

Efficiency + Operating Costs Once the operating parameters (including required linear power) of a customer's amplifier have been determined, a like-for-like comparison between amplifier technologies can begin to be made. Most operators will be interested in operating costs, size and weight, along with capital cost, reliability and serviceability. One of the critical elements of any amplifier is its efficiency, which always manifests itself in prime power consumption and heat generation, both of which affect the weight and size of an amplifier. Comparisons of efficiency have always been made between KPAs, TWTAs and SSPAs.

TWT technology continues to be a key player in the industry, on the ground and in space, primarily because the technology has evolved and improved steadily over the years. Solid state technology has also made significant improvements. Low power (i.e., up to 200 W Past) applications have largely become the territory of solid state. In today's market, "The Next Big Thing" is Gallium Nitride (GaN)-based solid state amplifiers which, like their Gallium Arsenide (GaAs)-based predecessors once did, present a new and interesting question in respect to their position against TWTAs and KPAs. This article examines the relative merits of GaN versus tube technology, assesses recent claims made extolling GaN technology, compares technologies on a "like-for-like" basis, and draws conclusions about the most appropriate applications for each technology. (9)

Technology is innovative spirit has made us the world is faster growing supplier of tube based HPAs. E.g. Xicom has fostered an impressive list of accomplishments:

1-Introduce super cool

Liquid cooling technology, lunched airborne SSPAs for in cabin and out of cabin solution. (10)

2-Super power TWT Amplifiers. (11)

3-GaN-Based SSPA product line. (12)

Spurious Signals

Spurious signals generated by the power amplifier tube fall into two major classes:

1. Broadband noise

2. Coherent spurious signals (TWTs have Noise Figures of about 40 dB; Klystrons will exhibit Noise Figures of approximately 35 dB.)

Solid State Power Amplifiers (SSPAs)

Advances in field effect transistor (FET) technology, particularly Gallium Arsenide FETs (GaAsFETs), have significantly impacted satellite communications, Earth station as well as spacecraft applications.

SSPAs are available today to replace TWTs in Earth stations and in the new generation satellites (all solid state). SSPAs offer the following advantages over TWTAs.

a. Superior intermediation distortion performance

b. Higher reliability

c. Lower maintenance costs

d. Lower cost for spares

e. Longer operating life compared to TWTA (one SSPA outlasts several tubes)

f. Higher personnel safety - no dangerous high voltages

g. Lower power consumption

Lower total cost of ownership GaAs is the substrate material for Metal Oxide Semiconductor FET (MOSFET) amplifiers due to the following factors. (11)

HPA Sizing

The link budget calculations are made considering each carrier separately. However, when deciding the required HPA size, the total EIRP for all carriers must be taken into account, together with the required back off For example, if the HPA transmits two carriers having EIRP1 and EIRP2 levels, then the total EIRP is calculated converting the two carrier powers to Watts. After calculating the total power required at the antenna input, the feed losses and output back off of the HPA must be taken into account.

HPA sizing calculation

$$(EIRP)SAT = C/T - G/T + Lod - Jd + Margin$$

$$OBO = (EIRP)SATURATION - (EIRP)OPERATION$$

$$IBO = OBO + X$$

Uplink operational flux density (OFD or illumination level W)

$$W = Saturation\ Flux\ density - IBO$$

$$EIRPdBW = W + Lou - G1m2 - Ju + Margin.$$

The power required from the HPA will be (7):

PHPA = EIRP - G + feeding losses

EIRP Total through HPA (EIRPt) =10*LOG(10^(EIRP1/10)+10^(EIRP2/10))

$$Power\ required\ at\ HPA\ output\ (Preq) = EIRPt - Gant + Lf$$

$$Saturated\ HPA\ output\ power\ (Ps) = Preq + PAOBO$$

$$HPA\ Size = 10\hat{}(Ps/10)$$

Distance to the Satellite

The distance between an E/S and a geostationary satellite is:

$D^2 = R^2_0 + R^2 - 2\ R\ R_0\ COS\ (\Phi)$

Where:

d = distance from Earth station to satellite
R = distance from satellite to center of Earth = 42,164 Km
Ro = radius of Earth (6,378 Km)
Φ = Great circle angle = arcos (cos (x).cos(Y))
X=Earth Station Latitude
Y = Difference in Longitude between E/S and satellite.
Free space loss:
Lo = 20 log D + 20 log f + 92.5 dB

Where:

D = distance in km between transmitter and receiver, or slant range

f = frequency in GHz

92.5 dB = 20 log {(4π*109*103)/c}

Results

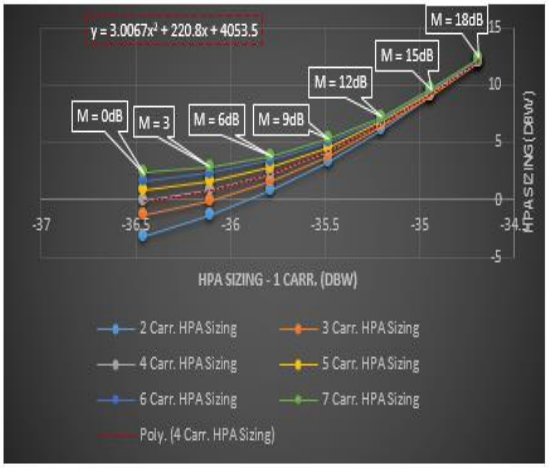


Figure (1)

Show the effect of margin in the HPA sizing through the different carrier types. The margin at specific value canceled the HPA increment and easily can accepted greater numbering of the carrier.

The figure is example of 7 carriers with different margins, to show the effects of these margin in the number of carriers.4 carriers is average, so we are concentrated in only 4 carriers, so the approximately mathematical equation:

Required HPA sizing for MC. = 3 (SC. Requirement)^2 + 220.8 SC requirement + 4053.5

the study is revealed that, by knowing the HPA sizing required for SC., easily we can detected the required for MC. (approximately), but as we show from fig., the increasing in the margin means we creeping toward the accurately.

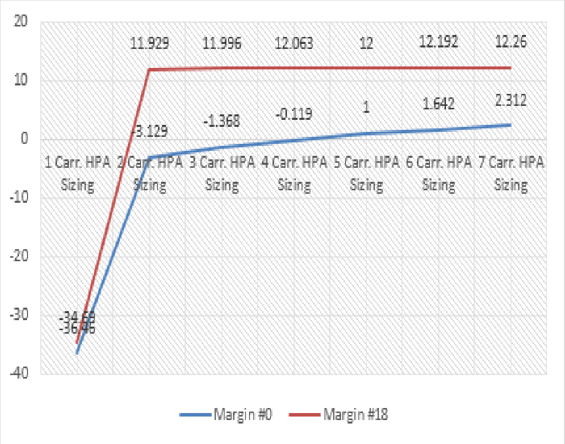


Figure (2)

Show the effect of margin (0 dB and 18 dB) in the HPA Sizing at different carriers. The variation in single is found to be 1.77 dBW, where it found to be 9.948 dB for 7 carriers, this means it is direct effect. So, it is easy to control in carrier number by both margins up or down link.

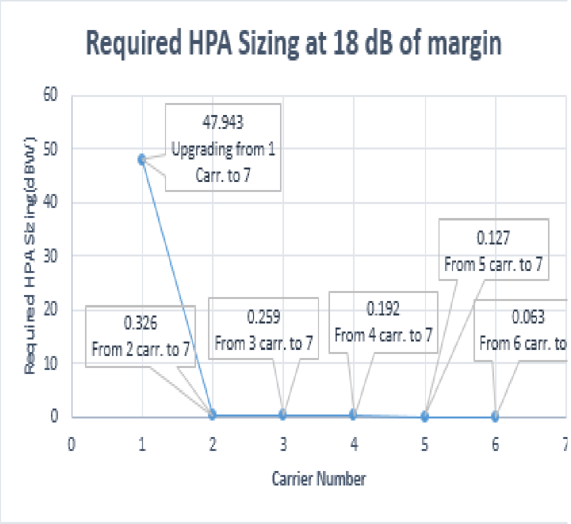


Figure (3)

From figures (3) and (4):

a. The roll of margin in upgrading from SC. To MC, this is accomplished by additional HPA sizing is needed, at the absence of margin, 33.33 dBW of HPA sizing is required, but at 18 dB of margin , 46.62 dBW of HPA sizing is required.

b. The roll of margin in increasing the number of carriers for MC. the study revealed that, at absence of margin, 5.44 dBW of additional HPA sizing is required, but at 18 dB of margin, Just 0.326 dBW of additional HPA sizing is required

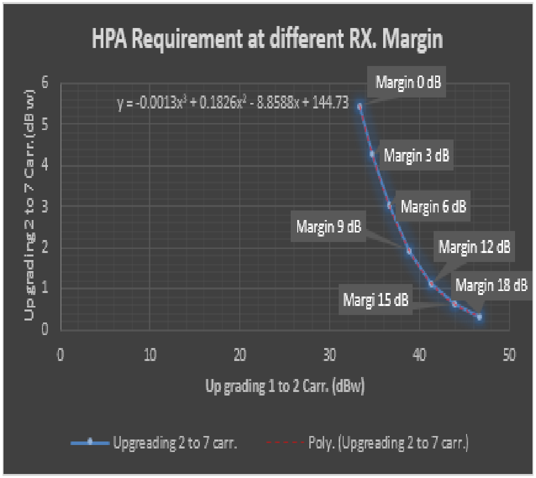


Figure (4)

Figure (4) show that:

Revealed that, the mathematical representation:

$$\begin{aligned} Upgrad\ 2\ to\ 7\ carr. \\ &= -0.001x^3 + -0.183x^2 \\ &\quad - 8.859x + 144.73 \end{aligned}$$

Where:

X is upgrading from SC. To MC.

The effect of margin according to:

Table 1: Upgrading vs. Margin

Upgrading from SC. To MC	Margin
33.33 – 34.73	3
34.74 – 36.70	6
36.71 – 39.10	9
39.12 – 44	12
44.01 – 46.62	15
Greater than 46.63	18

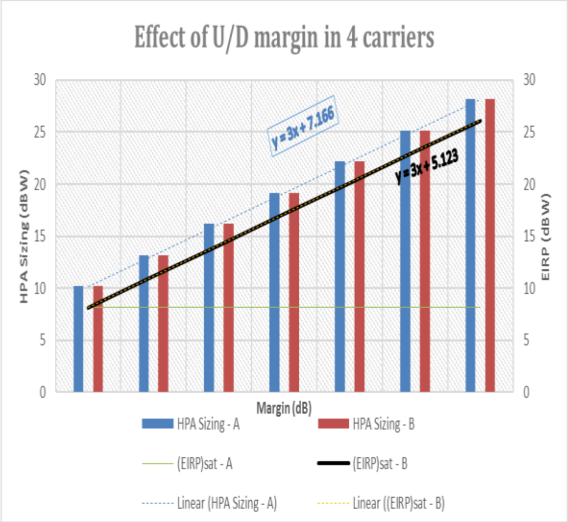


Figure (5)

Show that the two types of the margin (up/down) have the same effects in the determination of HPA size, (A) for receive site margin and (B) for transmit margin.

Once EIRP (A) is linear, the margin has no any effects in received site (ensuring for truth).

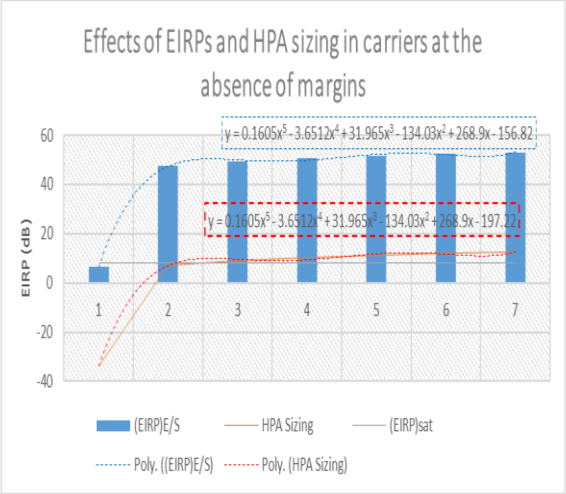


Figure (6)

Show the effects of EIRPs and HPA sizing in the carriers at the absence of margins. Obviously, no effects in the EIRP from satellite toward the ground (linear), but that radiation toward a satellite is varied according to carrier.

But, when we increased in margin to 15 dB, for different carriers (up to 7 carriers), for SC. negative value of HPA sizing is achieved

(- 33.655 dBW) and 6.44 dB of $(EIRP)_{E/S}$, but positive is obtained for MC. HPA.

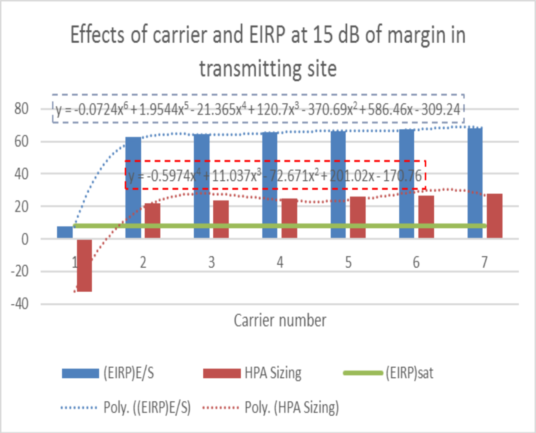


Figure (7)

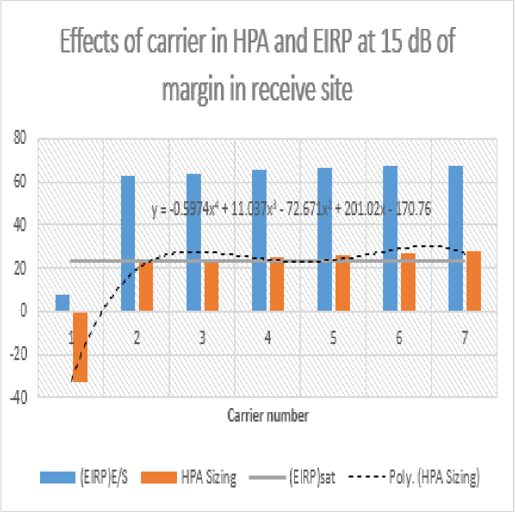


Figure (8)

At 15 dB of margin in the both site:

a) No changes in HPA sizing and the mathematical equation is :

$$\text{HPA sizing} = -0.6X^4 + 11.03X^3 - 72.61X^3 + 201.02X^2 - 170.76X$$

Where:

X is number of carrier.

No changes in (EIRP)E/S and the mathematically:

EIRP (dB) = $-0.07X6 + 1.95X5 - 21.37X4 + 120.7X3 – 370.69X2 + 586.46X – 309.24$

Where:

X is number of carrier.

Changes in the (EIRP)sat by value of the margin.

Conclusion

A HPA sizing and EIRP have significant effects in carrier types and the margin is played important role in controlling the both. by HPA sizing with the help of margin we ensuring that, important of carrier type (SC or MC) in the link budget calculation.

This paper has investigated the significant effects of margin in the number of carriers, by knowing the HPA sizing required for SC., easily we can detected the required for MC. exactly at higher value of the margin. Through the margin, carrier numbering be controlled for specific value of HPA sizing.

Upgrading from SC. To MC. is accomplished by additional HPA sizing, at the absence of margin, 33.33 dBW of HPA sizing is required, but at 18 dB of margin, 46.62 dBW of HPA sizing is required, on the other hand, increasing in number of carriers, the study revealed that, at absence of margin, 5.44 dBW of additional HPA sizing is required, but at 18 dB of margin, Just 0.326 dBW of additional HPA sizing is required, this reflect the both, significant roll of the margin and the important of distinguish the type of carrier (SC. Or MC.) in the link budget calculator.

Up and down link margins have the same effects toward the HPA sizing.

The study ensured that, up and down margins have the same effect in HPA sizing and (EIRP)E/S, and effected in (EIRP) sat by the value of margin.

All above accomplished by choosing an appropriate of parameters.

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