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Utilization of GaN HEMT in Power Amplifiers for Green Communication systems

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Abstract - **This paper proposes a new model of GaN HEMT transistor that can be utilized and used in the design of power amplifiers for green communications. The GaN HEMT transistor achieves very high power densities and breakdown fields. The designed power amplifier based on the GaN transistor is applied and tested on a WiMAX standard. The results of the experiments are compared with the conventional GaAs in the same application. Criteria such as: transmission mask, output power, power gain, 1dB compression point, drain efficiency and adjacent channel power ratio are used in the comparison. Both circuits are designed, validated and verified using ADS simulation tool. In this paper it has been proved that the proposed model compliances with green communication requirements. The results show that efficiency is actually doubled while the maximum output power is enhanced by 7dB. In addition, the adjacent channel power ratio is increased by (15-20) dB.**

Index Terms*—power amplifiers, *WIMAX application, GaN HEMT transistor

I. INTRODUCTION

As the world is moving towards reduced transmission power dissipation and reduced radiation, new design of power amplifiers are necessary. This is because that power amplifiers are the bottleneck in the transmission path. Green Communications vision is to reduce overall energy consumption within framework of optimizing system capacity and maintaining user Quality of Service(QoS) [1][2]. Therefore, when comparing system designs and improvements in energy efficient components the reduction of greenhouse gases alone is not adequate. The QoS must be considered in tandem with energy efficiency. Most wireless networks so far have been designed to maximize spectral efficiency (SE), which can be defined as the overall system throughput per unit bandwidth in b/s/Hz. However, modern and future green wireless systems need to be carefully designed so that energy efficiency (EE) is maximized. Therefore, we call a wireless network green when it uses the least amount of power to transmit a given amount of data while satisfying specified QoS requirements [2],[4]. In addition general standards as well as application oriented standards are developed for specifying the spectrum mask and dedicate the adjacent channel power ratios of specific RF outputs such as WCDMA, WiMax and LTE [5]. Information and communications technologies (ICT) are considered the fifth largest industry in power consumption [1], [3]. Fig.1 shows normalized Energy consumption as in both Fig.1 (a), and Fig.1 (b) [2],[3],[6],[7].

A base station (BS) usually consists of three major components: the baseband unit, the radio and the feeder network. Among these elements, the radio accounts for around 80% of a BS' energy needs, 50% of which is consumed by the power amplifier (PA) [2], [3], [8].

In this paper, the power amplifier spectrum mask and efficiency enhancement are adopted because of their great effect in the overall system power consumption. The properties and benefits of GaN transistors are in Section II. Therefore, a conventional power amplifier design application in WIMAX for power amplifiers used in green communications is introduced to obtain clean and efficient RF power shown in section III. Section IV presents the Proposed WIMAX Power Amplifier (PA) circuit Design based on GaN transistor output stage, while conclusion are provided in section V.

(a) ICT energy compared (b) Energy consumption

Fig. 1: Normalized Energy consumption

II. PROPERTIES AND BENEFITS OF GAN/ALGAN HEMTS

Wide band gap semiconductors such as GaN and SiC are very promising technologies for microwave high power devices. The advantages of these materials over conventional semiconductors, GaAs and Si, include high break down field (E_g), high saturation electron velocity (v_{sat}) and high thermal conductivity. GaN/AlGaN high electron mobility transistors (HEMTs) offer even higher power performance due to the higher carrier sheet density and the higher saturation velocity of the bidirectional electron gas channel (2DEG) compared to SiC metal semiconductor field effect transistor (MESFETs).The maximum band-gap determines the possibility of a transistor's work at high levels of activating influences (temperature and radiation).Very high electron density in the area of two-dimensional electronic gas and a high saturation field electron velocity make possible high channel current density and high transistor's gain. The maximum critical breakdown field allows realizing breakdown voltages of 100 to 300 V

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and increasing the working DC voltage up to 50-100 V, which together with a high current density provides for power density of industrial GaN transistors 4 to 8 W/mm (and up to 30 Watt/mm in laboratory samples), which is ten times greater than the output power density of GaAs transistors. GaN HEMT devices provide a very high ratio of peak current to output capacitance, as well as an extremely high breakdown voltage and power density capability. This unique combination of characteristics allows designers to achieve higher overall amplifier performance compared to competing devices [9]. Therefore, this paper introduces a proposed GaN based RF PA instead of GaAs based conventional one to improve maximum output power, efficiency, linearity and output spectrum mask.

III. CONVENTIONAL POWER AMPLIFIER (PA) DESIGN FOR WIMAX APPLICATION

The unit transistor cell size selection is based on a compromise between gain and power, because large devices have higher power. Moreover, input and output impedances decrease for larger devices, making the design of broadband matching networks difficult. The lack of power of small devices can be solved by combining several devices in parallel. It is worth noting that the complexity of the design increases with the number of cells to be combined. As a result, a good compromise between linearity and efficiency should be taken. Fig. 2 shows a conventional RF PA block diagram contains the input matching, preamplifier, interstage matching, output power amplifier, and output matching. Once the transistor size is selected, the available unit cells have to be evaluated at different bias operating conditions. This section concerns with the design and simulations of a class A power amplifier based on AlGaAs/GaAs. Circuit Level Power Amp design build up two stages, the first stage represents the preamplifier, biasing circuit and matching circuit as showing in fig.3 and the second stage is the main amplifier in fig.4, every stage using GaAs transistor model NEC 900175[10]. The power amplifier operates in frequency range 3.2 GHz to 3.8 GHz WIMAX standards using Agilent ADS simulator for p… ce… n.

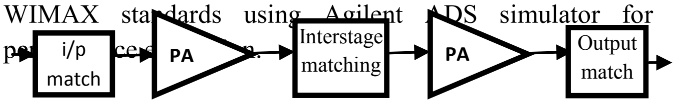

Fig .2: block diagram of two stage power amplifier

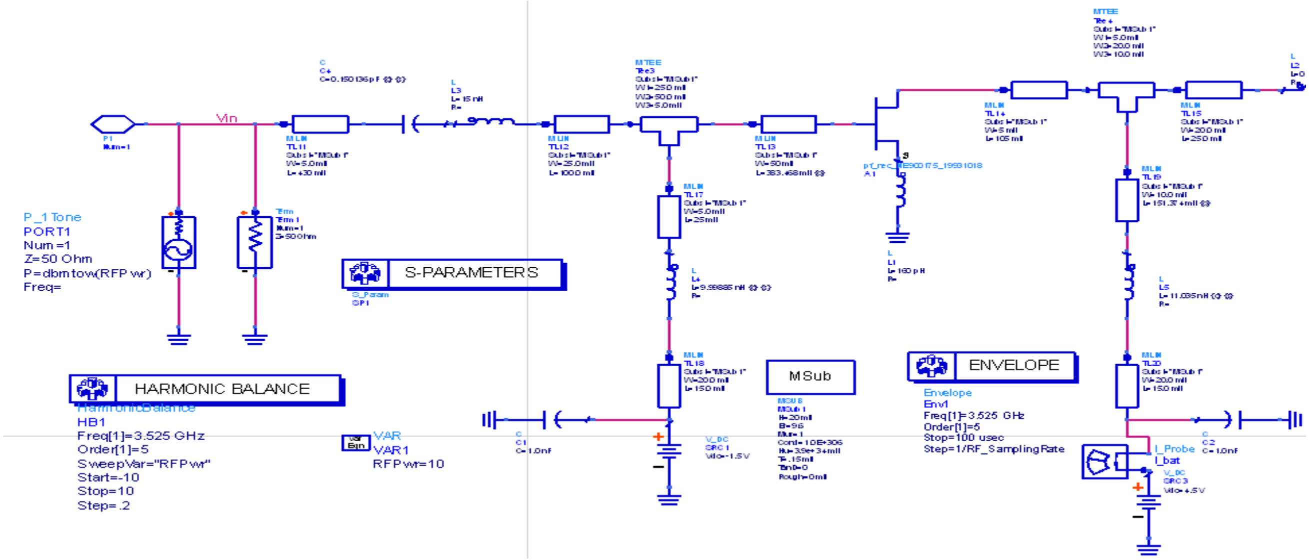

Fig .3: Prepower Amplifier Circuit Level Using Tansistor AlGaAs/GaAs (NEC900175)

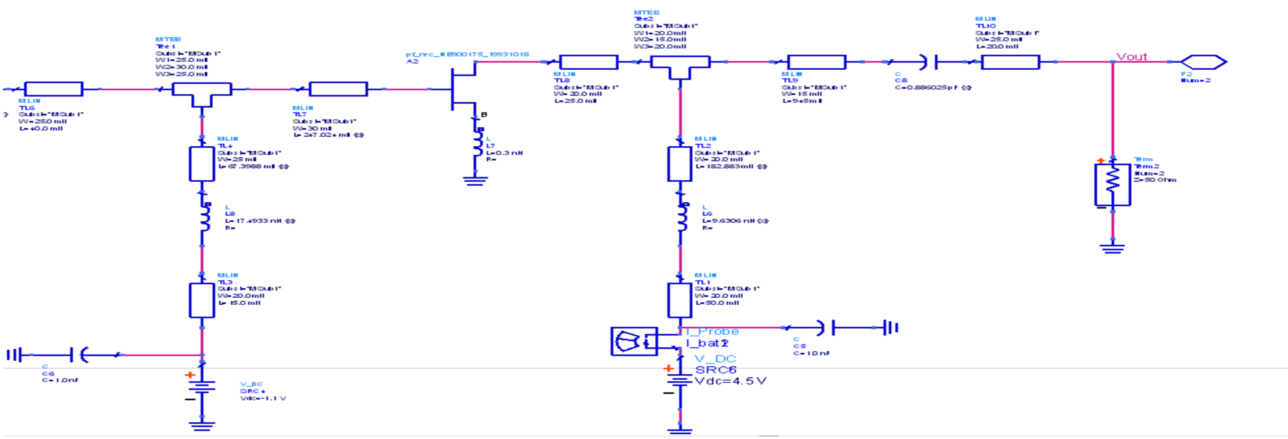

Fig. 4: Main stage power amplifier circuit level using transistor AlGaAs/GaAs(NEC 900175).

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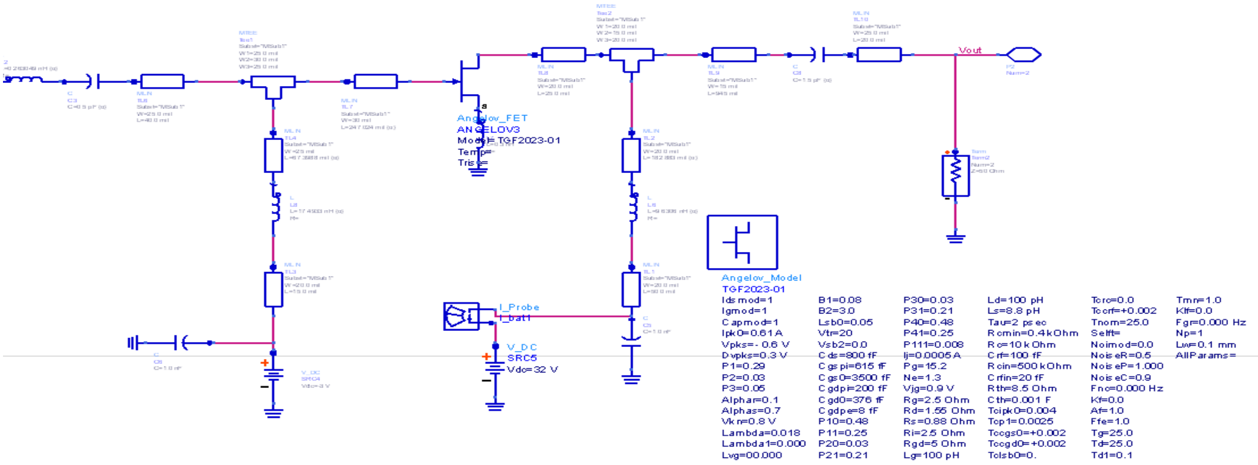


Fig. 6: power amplifier circuit level using transistor AlGaN/GaN(TGF 2023-01).

Gain versus frequency

Fig. 10 explains the gain and return losses versus frequency. One can notice that the gain is nearly constant according to the wideband operation and the minimum losses at the frequency from 3.3 GHz to 3.4 GHz.

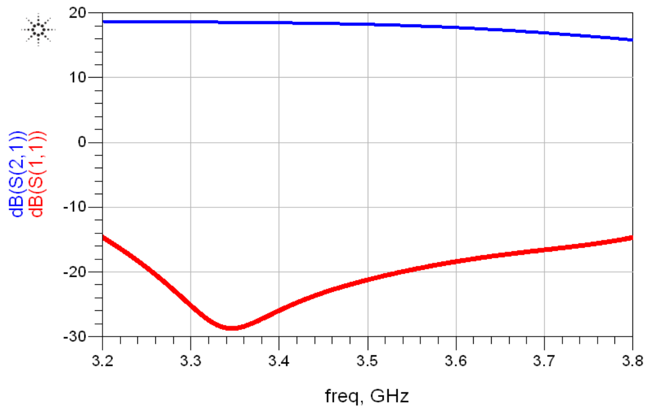


Table 1: Specification parameters of transistor

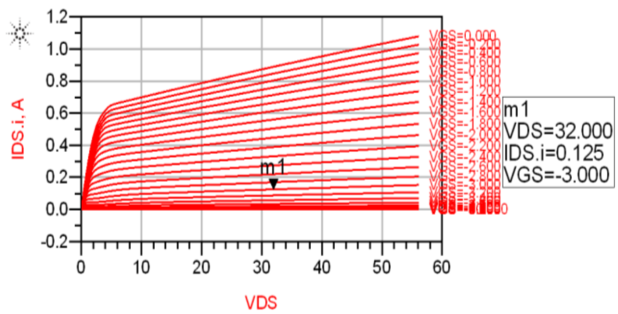
Parameter model	PAAlGaAs/GaAs	AlGaN/GaN
Frequency rang	Dc-up to 20GHz	Dc-up to 18GHz
Output power	23dBm	38dBm
Size	750um	0.25 um
Power added efficiency	27%	55%
Gain	7dB	15 dB
Application	Space amplifier and oscillator	Space amplifier ,military, broadband wireless
Input power	11dBm	26dBm

IV. PROPOSED WIMAX PA CIRCUIT DESIGN BASED ON GAN TRANSISTOR OUTPUT STAGE

The idea of the proposed PA is to utilize a GaN HEMT TGF2023-01[11] transistor instead of GaAs HEMT NEC900175 to modify the linearity and efficiency as well as the optimizing the circuit for better output spectrum mask. The selection of the transistor is very important when we build up the circuit of power amplifier, so the specification of the two transistors is reported in the Table 1. The proposed output stage is shown in Fig. 6.

A. Nonlinear modeling of GaN transistor

The first step of design in the current work is setup the simulation model parameters shown in Fig. 6 to estimate the I-V characteristics shown in Fig.7. The results of these simulations decide about the first draft version of bias points. The model used in the current design is the Angelov model applied on TGF 2023-01 produced from Triquent Company. It is a new model used transistor is not available as a library in Agilent library .it is using ADS-simulations tool, to simulate the circuit design and DC biasing analysis**.** I-V curves help to see, for example, the operation region of a transistor, the maximum drain currents, threshold voltage, knee region, safety region, etc. Before building up the circuit, the maximum allowed DC power dissipation must be found in Fig. 7.



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B. Input matching and output matching

The optimization of impedance matching causing the optimum output power and optimum gain as shown in Fig.8.

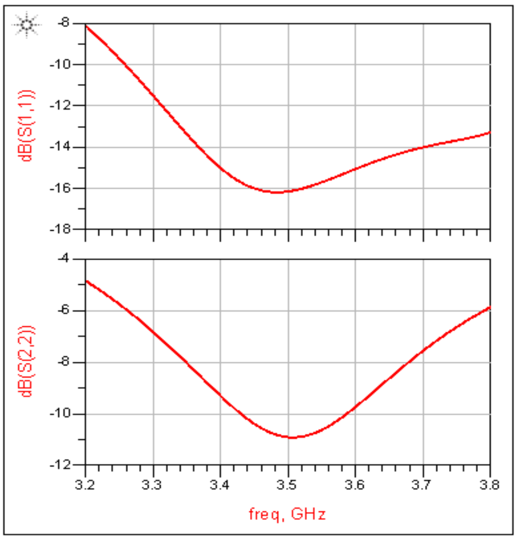

Fig.8 input matching and output matching

C. Gain versus frequency

Figure 9 will explain the gain and return loss versus frequency. It can be noticed that the gain is nearly constant according to the band, beside it is maximum and the minimum losses at the frequency 3.4 GHz to 3.5 GHz.

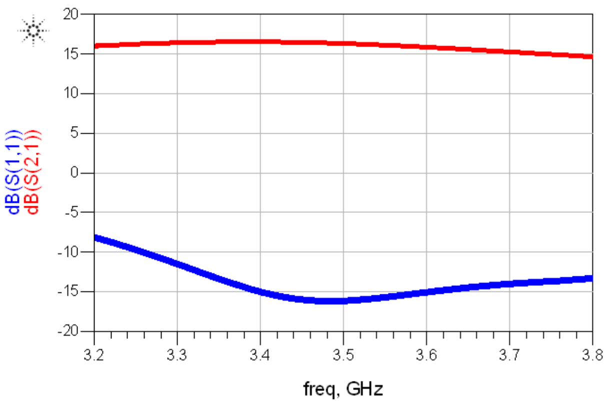

Fig.9: Gain and losses versus frequency.

D. WIMAX Verification using power amplifier based on GaN HEMT model

It is using a real circuit-level power amplifier based on GaN HEMT model, and verifying it by a realistic WIMAX source shown in Fig.10. The verification test bench is 100% compliant with the WIMAX standards and the verification is 100% true and accurate and is done on the circuit level PA. Therefore a typical power amplifier is selected from WIMAX applications to check its output transmission spectrum mask in Fig.11, and compares it to the required specifications by WIMAX.

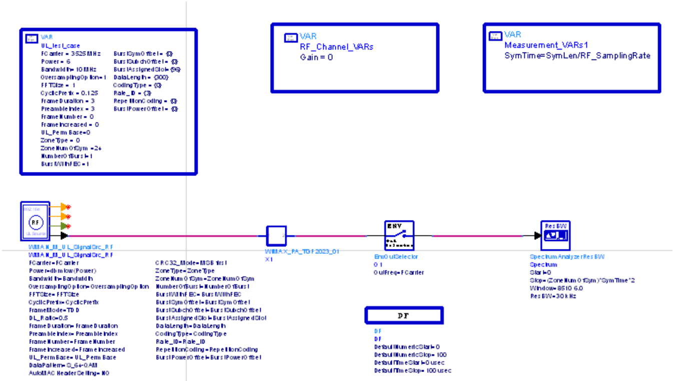

Fig.10: Test bench of WIMAX Verification using power amplifier based on GaN HEMT model

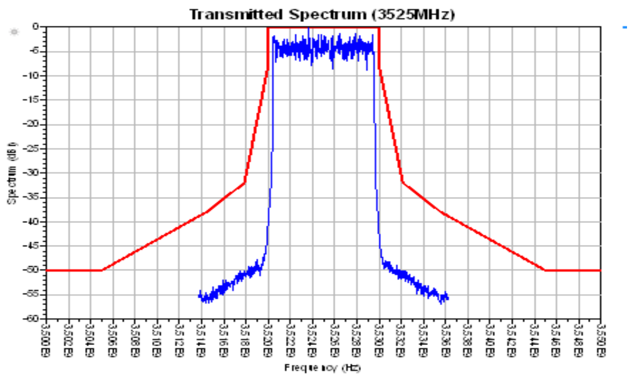

Fig.11 Transmission Mask output spectrum of WIMAX test bench.

V. Comparison result between power amplifier based on GaAs and GaN transistor & verification for WiMax Application

The spectrum output power using GaN HEMT is concentrated inside the standard mask, it means that the interference probability decreases caused output power increase and the difference between the spectrum output powers using GaAs HEMT by 15 dB as shown in Fig.12. The efficiency is doubled while the maximum output power is enhanced by 7dB. We call a wireless network green when it uses the least amount of power to transmit a given amount of data while satisfying specified QoS requirements. The need for green design in future wireless networks is extremely important due to the worldwide growth of mobile subscribers and delay-tolerant data traffic .Modern wireless devices are continually adding support for high data-rate “killer” applications that require a large amount of power at the BS since the bandwidth is limited. According to Shannon’s theorem, the data rate can be increased by increasing either the bandwidth or the power. In this case takes the other side of stress talking on the output power,

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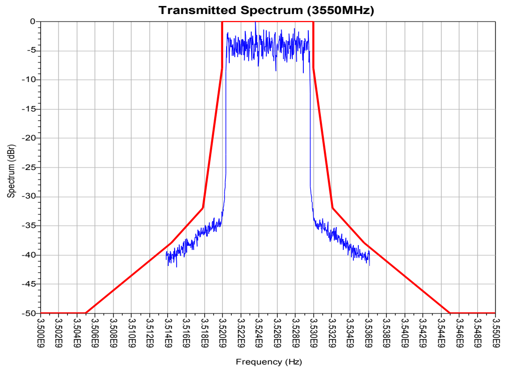
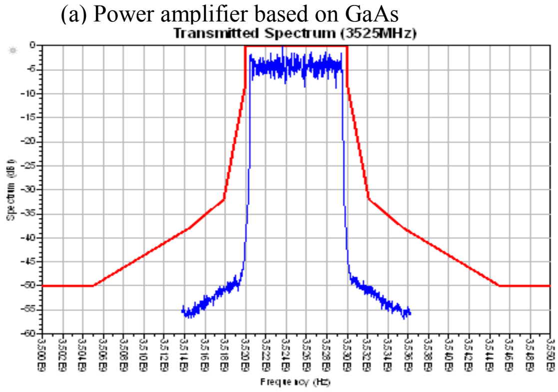
and select the point from input at 8 dBm and notice the output power as shown in Fig.13. The comparison result between two power amplifiers as shown in table 2.

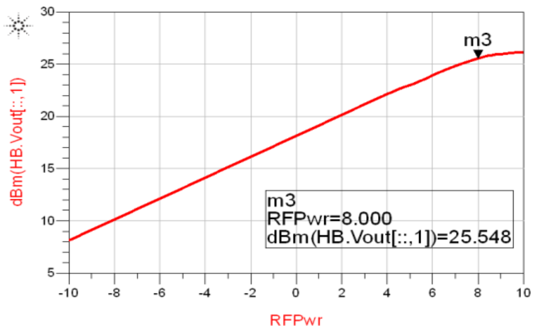


(a) Power amplifier based on GaAs

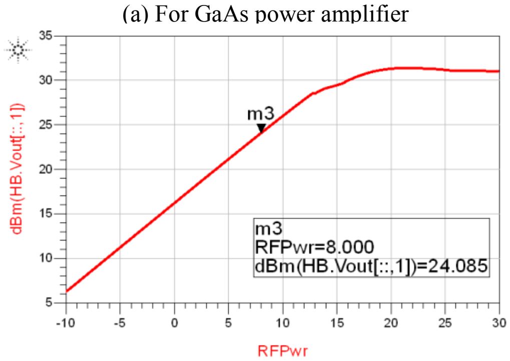


(b) Power amplifier based onGaN

Fig. 12: Transmission mask



(a) For GaAs power amplifier



(b) For GaN power amplifier

Fig. 13: Output power versus input RF power

Table 2: comparison between Conventional design and proposed design & verification for WiMax Application

Parameter model	Conventional design	Proposed design	Enhancement
Max.output power	25dBm	32dBm	7 dB
Adjacent channel power ratio	35dBr	50-55 dBr	15 dB:20dB
Gain	18dB	16.5dB	-1.5 dB
Drain Efficiency	16%	32%	Doubled

VI. Conclusion

The proposed model of GaN HEMT transistor has shown enhancement in efficiency, linearity, output power, and spectrum transmission mask in the adjacent channels. It has also shown enhancement of the 1dB compression point. This has led to reduced radiation and has proved its suitability in green communications systems. This means that the new model of GaN HEMT can be used instead of a conventional GaAs Transistor. The efficiency is actually doubled while the maximum output power is enhanced by 7dB.In addition, the adjacent channel power ratio is increased by (15-20) dB which makes the transmission mask deeply complies with the WiMax standard.

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