Correlation and MEG properties of Genetic Dual Parallel Printed Dipole antennas in Wireless applications

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***Abstract*— In wireless communications, the multipath propagation effect degrades usually the system performances. Several methods have been studied to mitigate this phenomena, among others, antenna diversity. This technique can overcome the multipath fading improving the overall performance of communication system. In order to study the impact of the wireless channel and perform antenna diversity, two parameters must be evaluated: the mean effective gain, and the correlation coefficient between the antennas. Parallel Printed Dipole antennas have been succesfully used in mobile base station development, showing either broadband or multiple-band properties besides its low cost. However, the previous parameters have not been analysed since these antennas have not been yet considered in mobile devices. In this paper, two dual-printed dipole antennas for ISM applications operating in 2.4-2.4835 Ghz and 4.9-5.875 GHz frequency bands are presented. Genetic Algorithm optimization (GA) is applied first, to a classical dual band printed dipole antenna schema. Later on, a pre-fractal technique is proposed on the larger strip and electromagnetic parameters are re-optimized to achieve a more compact radiator. Frequency performance of both antennas is introduced showing a VSWR<1.5 for a input impedance of 50 Ohms. Mean effective gain (MEG) is worked out considering traditional ISM scenarios. Results for both antennas for typical indoor and outdoor environments are given using the statistical angle of arrival behavior of such environments. Finally, an antenna diversity cell is designed considering the pre-fractal dipole as unitary element and the correlation properties are evaluated.**

I. Introduction

In the last few years, the development of wireless technologies was one of the main research focus in the information and communications field. Therefore, a strong effort in antenna design to provide wireless coverage with low cost has been a key factor to accomplish this development. Additionally, the demands of industrial, scientific, and medical (ISM) bands are increasing. Some of the desired features of these antennas include broad bandwith, simple impedance matching to the feed line and low profile.

In this paper, a radiating element is designed to adopt the standard printed circuit board (PCB) substrate and production technology. The uniqueness of the design comes from an evolving optimization procedure applied to a classical dual printed dipole antenna (DPDA) [1] used previously in 2 and 3G base station systems combined with a pre-fractal topology [2] to reduce the size. Additionally, since the antenna is oriented to be used in a mobile device, a traditional approach to evaluate the electromagnetic performances is not enough to predict the overall behavior in a wireless scenario. The Mean Effective Gain (MEG) [3], is a recently defined parameter to include the mobile channel characteristics (those referred to spatial and polarization properties). This parameter is computed for the radiating elements placed in typical scenarios: indoor and indoor-outdoor urban.

In section II, the antenna geometries and design outlines are presented, showing the evolution of the GA applied. In section III, classical electromagnetic parameters (S-parameters, Gain) coming from the optimization are showed. In section IV , MEG results are presented. In section V, a polarization diversity antenna is designed. Finally, a conclusion is provided.

II. Parallel Printed Dipole Antenna Design with Genetic Algorithms

A. Antenna Geometries of PDA

Figs.1 and 2 show a schematic drawing of the antennas and the genes involved in the genetic optimization. In the classical DPDA, two printed strip dipoles of different lengths, with the arms printed on opposite sides of an electrically thin dielectric substrate are connected through a parallel stripline (PS). In the case of the pre-fractal printed dipole antenna (PF-DPDA), the first iteration of a fractal tree is applied to the longer element so that the size can be reduced. In order to achieve an optimal dual-frequency radiator, the line polarity between the radiating elements must be inverted. The antennas were designed on a dielectric substrate of heigh $h = 1.6$mm, relative permittivity $\epsilon = 4.5$ and loss tangent $\tan(\delta) = 0.02$.

B. Evolutive Optimization (GA) results

A genetic optimization method was applied for each geometry (DPDA PF-DPDA). Six and eight genes are codified

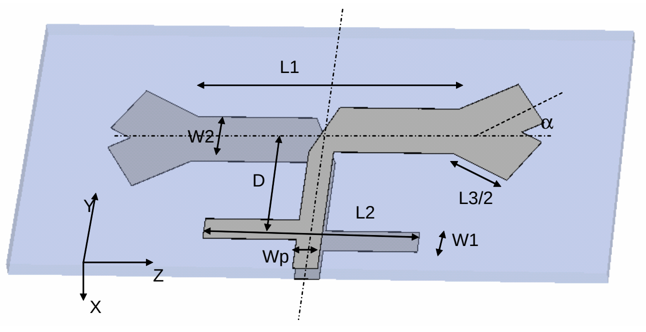

Fig. 1. PF-DPDA Layout and Geometrical parameters

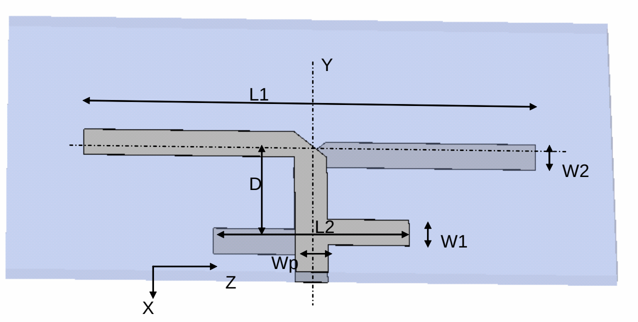

Fig. 2. DPDA Layout and Geometrical parameters

using 30 bits in a binary codification, respectively. A simple GA with typical parameters $p_{cross} = 0.65, p_{mut} = 0.01$, size population of 30 individuals was let to evolve during 150 generations in DPDA and 100 generations in PF-DPDA. The *Fitness function* was :

$$F = |R_{in}(\omega_1) - 50| + |R_{in}(\omega_2) - 50| \\ + |R_{in}(\omega_1) - R_{in}(\omega_2)| + |X_{in}(\omega_1)| + |X_{in}(\omega_2)| \quad (1)$$

where $Z_{in}(\omega_i) = R_{in}(\omega_i) + jX_{in}(\omega_i)$ is the antenna input impedance at ω_i frequency.

With this fitness function, a resonant 50Ω input impedance at both frequencies is looked for. The antenna parameters were simulated by a MoM solver. The frequencies chosen for ISM where 2.45 and 5.4 GHz. Table I shows the optimized parameters for each antenna and Fig. 3 the fitness function convergence towards the optimum.

As observed, computing the Size Reduction as

$$\text{Size Reduction} = \frac{L_1^{DPDA} - L_1^{PFDPDA} - L_3/2\cos(\alpha)}{L_1^{DPDA}} \quad (2)$$

a 27.55% of compactness is achieved thanks to the pre-fractal method.

III. Classical performances for the radiating configurations

The classical analysis of antennas comprises, among others, these main quantities: the S-parameters, impedance bandwidth and the gain radiation pattern.The S_{11} is plotted in Fig.4.

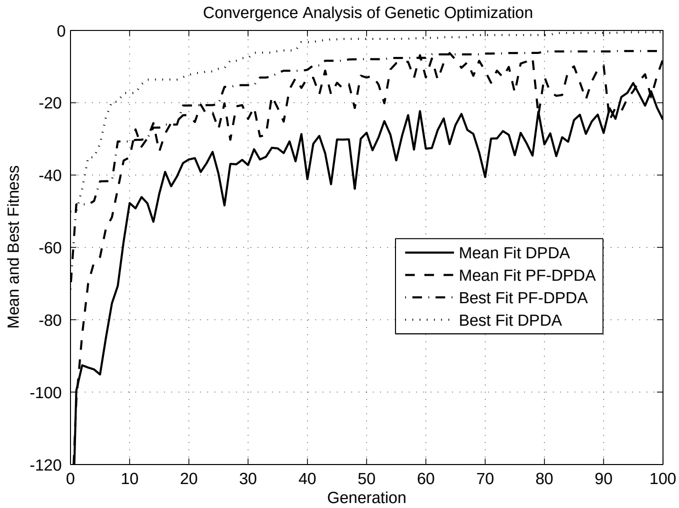

Fig. 3. Genetic Algorithm Optimization features for the antenna problem

TABLE I
Optimum chromosomes found by GA simple.

Gene	DPDA	PF-DPDA
L1(mm)	45.054	26.2694
L2(mm)	19.3643	21.3248
D(mm)	12.5259	13.2189
W1(mm)	5.5733	5.9203
W2(mm)	2.7896	2.5660
WP(mm)	2.9568	2.5019
L3(mm)	–	14.8525
α(deg)	–	30.9282

Considering a $|\Gamma| < -15dB$ as bandwidth criteria, it is obvious that the antennas are radiating in the whole ISM frequencies specified.

Regarding the pattern, Fig.5 and 6 represents the E and H plane cuts. It is observed that the antennas have almost an omnidirectional diagram in the lower band while in the upper band the pattern is more directive. Table II summarizes the classical performances.

TABLE II
Main Antenna Features

Paramater	DPDA	PF-DPDA
Bandwith ISM1 (MHz)	220	360
Bandwith ISM2 (MHz)	900	1455
Directivity ISM1 (dBi)	1.73	1.71
Directivity ISM2 (dBi)	4.6	3.38
Gain ISM1 (dBi)	0.54	0.67
Gain ISM2 (dBi)	1.11	0.52

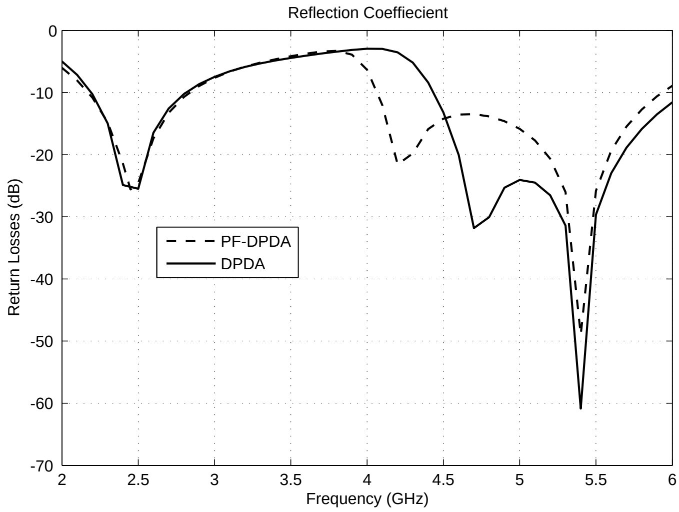

Fig. 4. Return Losses of DPDA and PF-DPDA

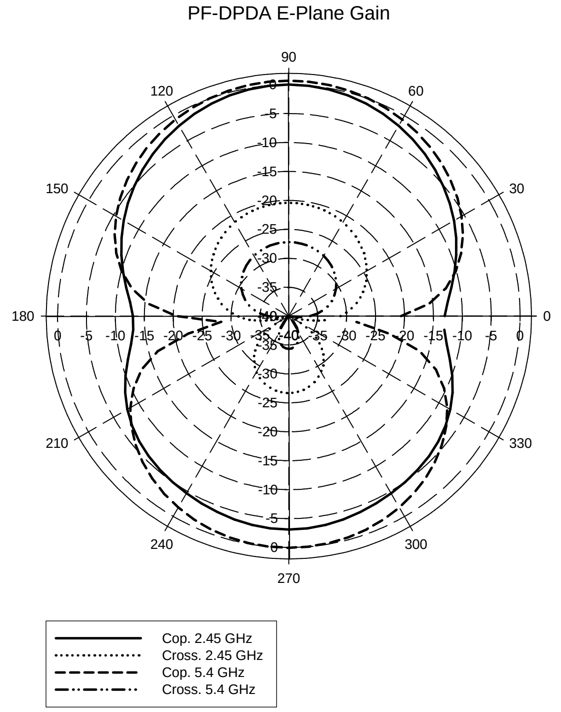

Fig. 5. Gain Pattern of PF-DPDA Antenna

IV. Effective Gain Analysis in ISM environments

A. Method of Analysis

As mentioned, the MEG is a statistical measurement of the antenna performance in a multipath enviroment. The mean power received from the antenna can be obtained from the radiation patterns and the statistics of the channel using this concept. The MEG of an antenna, which is defined as the ratio of the mean received to the mean incident power at the antenna, can be calculated from [4],

$$MEG = \oint \frac{\Gamma}{1+\Gamma} P_\theta(\Omega) G_\theta(\Omega)$$

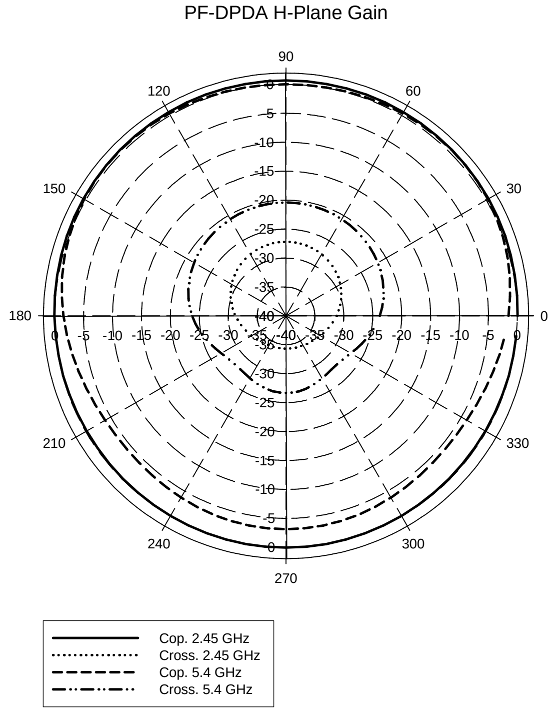

Fig. 6. Gain Pattern of PF-DPDA Antenna

$$+\frac{1}{1+\Gamma} P_\phi(\Omega) G_\phi(\Omega) d\Omega \quad (3)$$

where G_θ and G_ϕ are the θ and ϕ polarized components of the antenna power gain pattern, Ω is the solid angle (θ, ϕ), P_θ and P_ϕ are the θ and ϕ components of the angular density functions of the incoming plane waves. Γ is the crosspolarization power ratio, defined as the ratio of the mean received power in the vertical polarization to the mean received power in the horizontal polarization. The crosspolarization power ratio (Γ or also known as XPR) varies considerably, depending on the surrounding enviroment. Thus, these values must be concreted according to the mobile application of interest.

B. Incident wave statistics for ISM environments

As a result of the large amount of interest in the wireless channel, several probability density functions have been proposed [5], [6], [7], validated through measurements. First results were related to the temporal properties of the propagation environment, and finally, a focus in the angular power distribution motivated by the emerging MIMO systems has brought several models for the incident wave statistics. In the case of the XPR, it is shown that its value is between 0 dB and 9 dB in most cases, although in some environments can achieve 11 dB.

When an ISM indoor environment it is considered, two possible scenarios may be of interest:

1) Indoor environment: The antenna is assumed to be working inside a building. Measurements [8] have shown that the power azimuth spectrum P_ϕ is best modeled by a Laplacian function for both polarization. A Gaussian function for the elevation is assumed. Therefore, for the DPDA and PF-DPDA antennas:

$$P_\phi(\theta,\phi) = A_\phi e^{-\left|\frac{\sqrt{2}\phi}{\sigma}\right|} e^{-(\theta-[\pi/2-m_H])^2/2\sigma_H^2} \\ ,0 \le \theta \le \pi, -\pi \le \phi \le \pi \quad (4)$$

$$P_\theta(\theta,\phi) = A_\theta e^{-\left|\frac{\sqrt{2}\phi}{\sigma}\right|} e^{-(\theta-[\pi/2-m_V])^2/2\sigma_V^2} \\ ,0 \le \theta \le \pi, -\pi \le \phi \le \pi \quad (5)$$

For these pdfs, suitable statistic moments will be $\sigma = 24°, \sigma_H = 9°, \sigma_V = 11°$ and $m_V = 4°, m_V = 2°$. MEG will be study for XPRs between 0 and 11, although measurements point out values around 7 dB.

2) Indoor-outdoor environment: The antenna is assumed to be working outside a building, but close to the point access system. This corresponds to traditional gaussian pdfs in elevation and uniform distribution in azimuth. Therefore, for the DPDA and PF-DPDA antennas:

$$P_\phi(\theta,\phi) = A_\phi e^{-(\theta-[\pi/2-m_H])^2/2\sigma_H^2} \\ ,0 \le \theta \le \pi, -\pi \le \phi \le \pi \quad (6)$$

$$P_\theta(\theta,\phi) = A_\theta e^{-(\theta-[\pi/2-m_V])^2/2\sigma_V^2} \\ ,0 \le \theta \le \pi, -\pi \le \phi \le \pi \quad (7)$$

In both cases, A_θ and A_ϕ are constants that must fulfill:

$$\int_0^{2\pi}\int_0^{\pi} P_\theta(\theta,\phi)\sin\theta d\theta d\phi = 1 \quad (8)$$

$$\int_0^{2\pi}\int_0^{\pi} P_\phi(\theta,\phi)\sin\theta d\theta d\phi = 1 \quad (9)$$

For these pdfs, suitable statistic moments will be $\sigma_H = 8°, \sigma_V = 15°$ and $m_V = 1°, m_V = 2°$. MEG will be study for XPRs between 0 and 11, although measurements point out values around 11 dB.

C. Results

Fig. 7 shows results for MEG in indoor-outdoor environment, for both frequency bands. As expected, if XPR increases, the MEG is improving approaching to theoretical Gain. Comparing the indoor and outdoor meg, it is observed that meg is lower in indoor enviroments than in outdoor. This may be due to fact that the power contribution for incident waves slightly far from the center in azimuth (0 deg) are almost negligible if a Laplacian probability density function is considered rather than a uniform pdf.

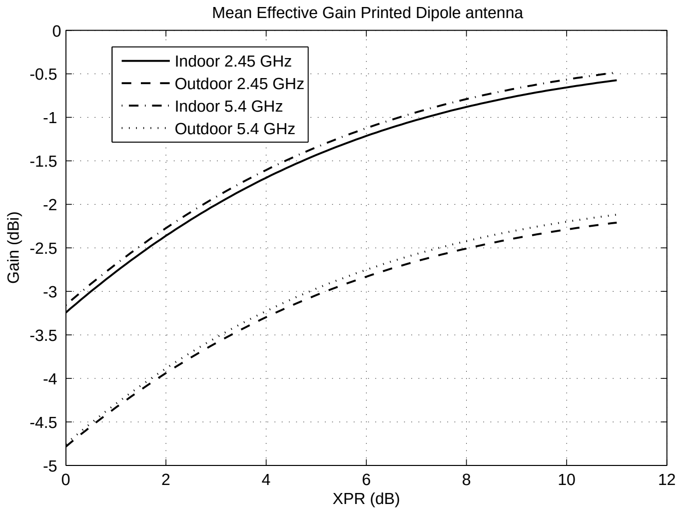

Fig. 7. MEG in indoor-outdoor environment

V. Correlation Analysis for Polarization Diversity Pre-fractal Cell

A. Analysis Method

In a two-branch polarization diversity antenna, performance is evaluated using the MEG of each branch and the correlation coefficient ρ. The expression of the correlation coefficient may be found in [9] and is given by

$$\rho = \frac{|R_{12}|^2}{\sigma_1^2\sigma_2^2} \quad (10)$$

where σ_1, σ_2 are the variances of received signals in branches 1 and 2 of the diversity antenna, computed as:

$$\sigma_i^2 = K\int_0^{2\pi}\int_0^{\pi} \Gamma E_{\theta i}(\theta,\phi)E^*_{\theta i}(\theta,\phi)P_\theta(\theta,\phi) \\ +E_{\phi i}(\theta,\phi)E^*_{\phi i}(\theta,\phi)P_\phi(\theta,\phi)\sin\theta d\theta d\phi \quad (11)$$

and R_{12} is the covariance between the two branches:

$$R_{12} = K\int_0^{2\pi}\int_0^{\pi} \Gamma E_{\theta 1}(\theta,\phi)E^*_{\theta 2}(\theta,\phi)P_\theta(\theta,\phi) \\ +E_{\phi 1}(\theta,\phi)E^*_{\phi 2}(\theta,\phi)P_\phi(\theta,\phi)\sin\theta d\theta d\phi \quad (12)$$

where subscripts 1 and 2 refer to the first and second branches of the diversity antenna (Vertical and Horizontal polarizations) and the symbol * denotes complex conjugate operation and K is a constant.

B. Polarization Diversity Cell with PF-DPDA antennas

In order to evaluate the diversity features of these dipoles, a two branch diversity has been simulated considering as prime element the pre-fractal parallel printed dipole. Fig 8 shows the structure with two PF-DPDA's, one rotated 90 degrees respect to the other.

The electrical features and coupling values are shown in Fig.9

If theoretical dipole antennas are considered, in this situation the correlation coefficient is 0. However, in the ideal situation the crosspolar component of the dipole is zero. In the PF-DPDA case, the crosspolar field is almost zero, but it is not zero, so it is expected a very low correlation coefficient. Fig. 10 plots the correlation coefficient for this cell when the an

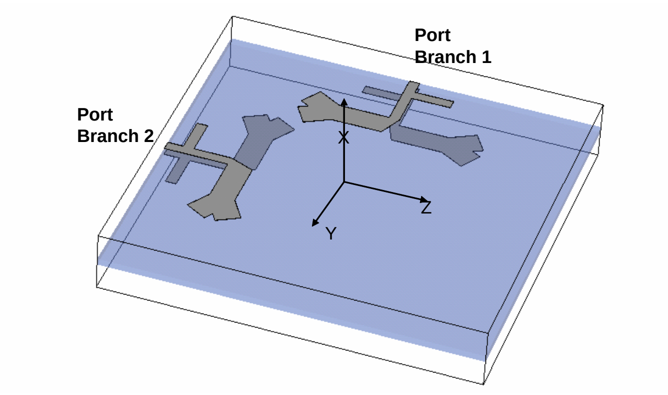

Fig. 8. Polarization diversity antenna using two PF-DPDA's

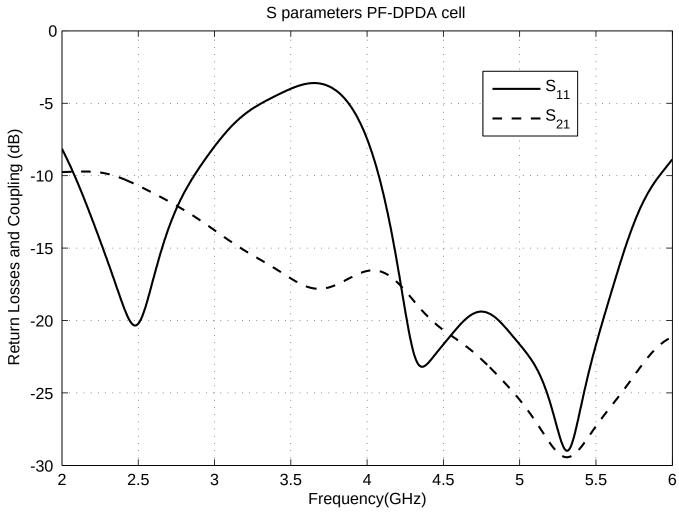

Fig. 9. Coupling between cell elements in polarization diversity schema

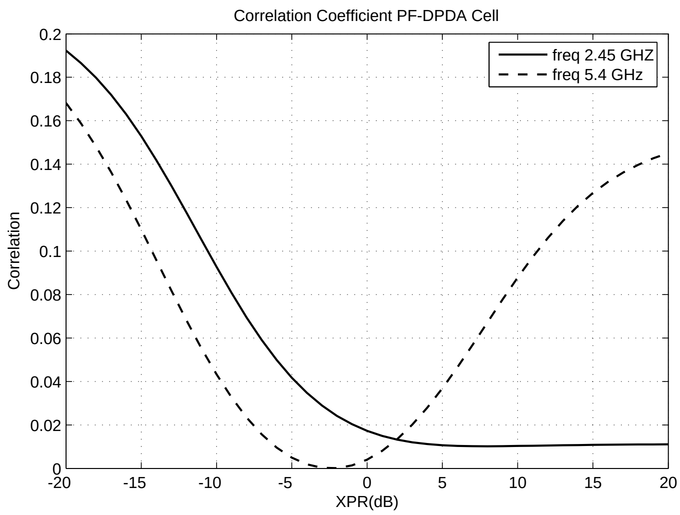

Fig. 10. Correlation between cell element anntenas

indoor-outdoor environment is considered for typical values mentioned above.

As shown, the cell behaves worse at lower frequency than at higher if $XPR > 0$. This may happen taking into account that the pattern is more directional at 5.4 GHz than at 2.45 GHz.

VI. Conclusion

This paper shows a novel genetically pre-fractal printed dipole antenna for ISM frequency band. The antenna is analyzed in classical terms showing good performances in both bands. Additionally, the gain performance is studied in wireless enviroments and a diversity polarization antenna is designed and evaluated in this scenarios. It is shown that the correlation coefficient is rather low, being able to be a candidate suitable for this kind of communications.

Acknowledgment

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