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Design and Fabrication of Triangular Patch Antenna for Airborne Radar Applications

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***Abstract*—For airborne applications, onboard antennas should have minimal weight and should be of low cost while maintaining optimal functioning over a wide spectrum of frequencies. An equilateral triangular patch antenna is designed, fabricated and tested as it is light-weight and cost effective. This antenna has been designed for operation in S-Band at a frequency of 2.4 GHz. Micro-strip Line Feeding technique is employed with a quarter wave transformer to impedance match the load and the transmission line to reduce losses in power and the results of the performance of the antenna are simulated using CEM software.**

***Index Terms*— UAV; CEM One Solutions; Photolithography; Microstrip; Taconic TLC-32; MATLAB.**

I. INTRODUCTION

Antennas play a important role in the functioning of radar. It radiates electromagnetic signals outward to identify the object and later receives the reflected signal and reroutes to ground station. Antennas which serve such purposes have been designed in this field. Currently, we are working on a triangular patch antenna since it is of lower weight and other determining factors. In this project, a triangular patch antenna has been executed on software, fabricated, tested and simulation results are obtained.

Frequently, image capture devices and other optical systems suffer by conditions like environmental factors (e.g., smoke, fog, dust), hindering their capability to identify different moving objects. This means they cannot work accurately and cannot provide proper results. Further, when detection is possible, appreciation and segregation using such systems tends to be computationally hard as signals which are light-based in nature must be handled continuously to extract the information and analyze the signals. We assume a solution to this problem is by designing a miniature radar system to identify objects.

A new radar has been developed with transition of signal with a wide and ultra-Bandwidths (UWB).It has the features of improved detection range measurement accuracy. It provides a narrow antenna pattern by changing the radiated signal characteristics and increasing the directivity and improvement in radiation pattern.

Unmanned aerial vehicle integration into the National Air Space will require the UAVs support detection and identification of other UAV-sized targets [1]. Sensors are generally not able to detect or identify other UAV-sized targets and, when detection is possible, considerable calculation strength may be required for successful identification.

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Many large scale radar installations use some kind of pulsed radar arrangement to extract the information regarding the targets [2]. However, these arrangements cannot be adopted for miniature UAV applications due to complexity, large minimal range and very less range resolution. These issues are resolved by the use of Continuous Wave (CW) radars. CW radar systems can be divided into two generalized forms: Frequency Modulated Continuous Wave radar (FMCW), and Doppler radar. The former utilizes periodic variations in frequency to determine the range to the target while the other one depends on the Doppler Effect to isolate the moving targets and determine their velocities with respect to the radar antenna, but it is not capable of determining the range to the target to the antenna.

The use of radar for determination of type of moving object currently in the modern scenario is not new. This methodology has been present in larger vehicles and buildings including most modern military aircraft and airport installations [3]. For vehicles that are large in scale, and especially in the case of turbine powered systems, identification is simplified by the certainty of sensing not only the larger streamlined components, but also the Doppler modulation created by the power source.

Equilateral triangular patch antenna has been illustrated and analyzed according to the cavity model and the resonance frequencies are analyzed to find the dominant mode among them [4]. Among the first five modes the first three modes are perpendicularly radiating modes with radiation patterns that appear identical and similar polarization characteristics. The most reasonable mode is chosen to be TM10. The experimental and theoretical results match satisfactorily. The distance can be ascertained so that, for a certain mode, it estimates the power required to make similar the characteristic impedance of the feed. If the antenna is to be used for several different modes, it is acceptable that the input impedances for these modes be almost similar and almost equal. It is curious to point out that by placing the feed at a suitable location the input resistances at resonances of the three perpendicularly radiating modes can be made to decrease in the range 50-100 ohms, which is desirable. Several antenna designs have been compared and the triangular shape is optimal in function.

II. MATH

The mathematical formulas for design analysis of triangular patch antenna using cavity model are quite lengthy. The derivations have been omitted [5].

A. Resonance Frequency

The formula for resonance frequency obtained from is given by

$$f_r = \frac{cK_{mn}}{2\pi\sqrt{\varepsilon_r}} = \frac{2c}{3a\sqrt{\varepsilon_r}}\sqrt{m^2 + mn + n^2} \qquad (1)$$

Where K_{mn} is the wave number associated with different modes and ε_r is the relative permittivity of the substrate. To determine the mode which is dominant i.e. the mode which has the lowest resonance we need to examine several resonant frequencies. Here K_{mn} which is the wave number is given by

$$K_{mn} = \frac{4\pi}{3a}\sqrt{m^2 + mn + n^2} \qquad (2)$$

For microstrip antennas the dominant mode is determined by placing resonant frequencies in ascending order which in turn is used to find the order of modes of operation. The expression for lowest order resonance frequency is given by

$$f_r = \frac{2c}{3a\sqrt{\varepsilon_r}} \qquad (3)$$

III. DESIGN

The proposed triangular insert feed patch antenna with quarter wave matching is designed at a center frequency of about 2.4GHz. The total size of PCB is selected to be 59mm x 98mm x 0.79mm.The antenna is fabricated on a TACONIC TLC-32 substrate. First the substrate is designed for the antenna whose dielectric thickness is up to specifications as shown in Fig. 1. The substrate of the antenna is then is meshed with ground plane as shown in Fig. 2. Then the normal are correctly oriented in the direction of current flow as shown in Fig. 3. The meshed parts allow for simpler correction. Meshing helps the current to be distributed on each of the vertical lines of the mesh uniformly whereas for a conventional patch the current density is high only at the edges of the patch. Thicker mesh lines give rise to a lower resonant frequency than thin ones.

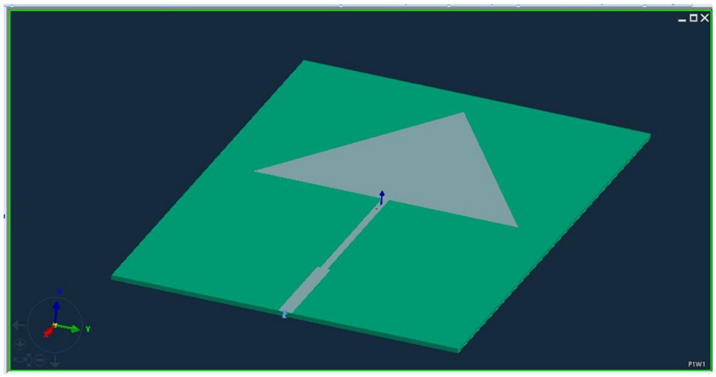

Fig.1 Substrate Design of Equilateral Triangular Patch Antenna in CEM One Software

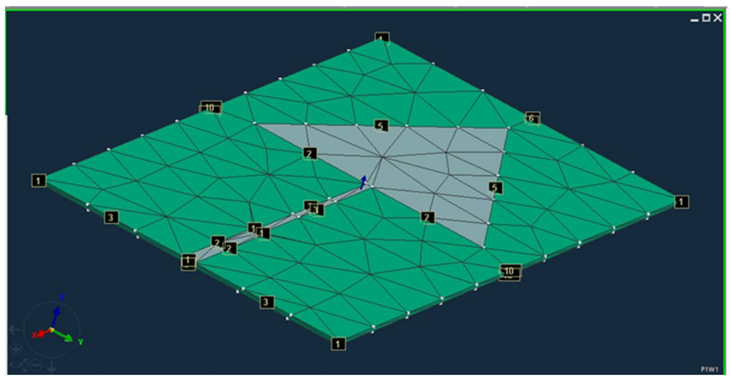

Fig.2 Meshing of the antenna with an element size of 0.0125m

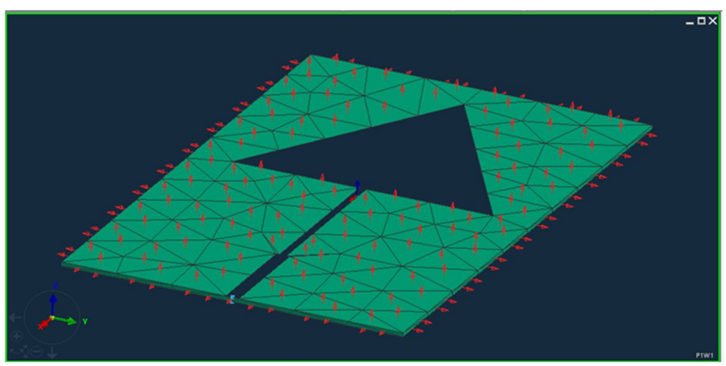

Fig.3 Correcting normals of the particular individual sides of the body of antenna

IV. FABRICATION

For fabricating the antenna the designed antenna specifications from CEM have been incorporated and the antenna is printed using photolithography which is used to pattern parts on the bulk of a substrate. The wafer is applied with photoresist using a spin-coating technique. The photoresist is then developed by removing some of it using a "developer" liquid. The upper part of the substrate is then etched and the portion which was not protected by photoresist gets removed. Then the photoresist is removed using a "resist stripper" so that the resist no long adheres to substrate.

V. THEORETICAL TEST RESULTS

In this section we are going to define the characteristics of the fabricated equilateral triangular patch antenna. The radiation pattern, VSWR, return loss and gain of the microstrip patch antenna are obtained. We have calculated the gain for triangular patch antenna and listed them in the results. The simulation of the design is carried out using ESI CEM One software. Fig. 6 shows the simulation for the return loss of the TMSA antenna.

A. Radiation Pattern

The radiating edges of a patch can be seen as two radiating slots placed above a ground surface and, assuming all radiation occurs in one part of the half of the sphere (on the patch side of the ground), we get a 3 dB directivity rise. This would be an antenna with a suitable ratio between the front and the back surfaces where all radiation propagates towards the front and no radiation is directed towards the back. The radiation pattern of the triangular patch antenna simulated by CEM One is shown in the Fig. 4.

B. VSWR

VSWR is defined as the measure of how well the antenna is impedance matched to the transmission line. It is a function of the reflection coefficient. In the Fig. 5 below the VSWR decreases to an efficient value of 1.8 at 2.43 GHz. This indicates that the transmission line and the antenna are impedance matched.

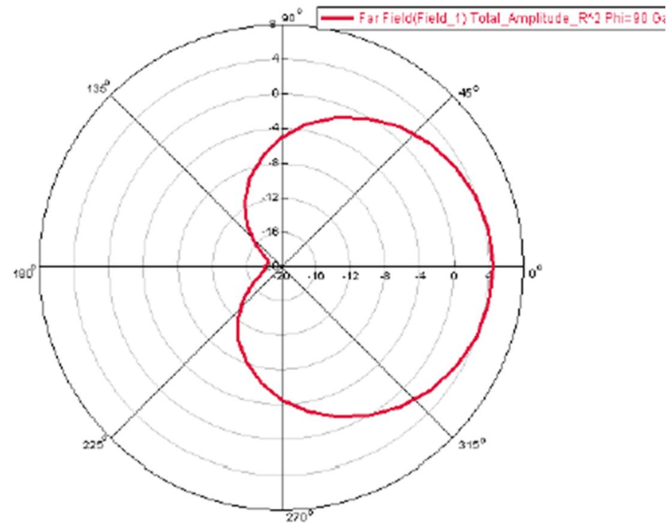

Fig. 4 Theoretical Polar Plot of radiation characteristics

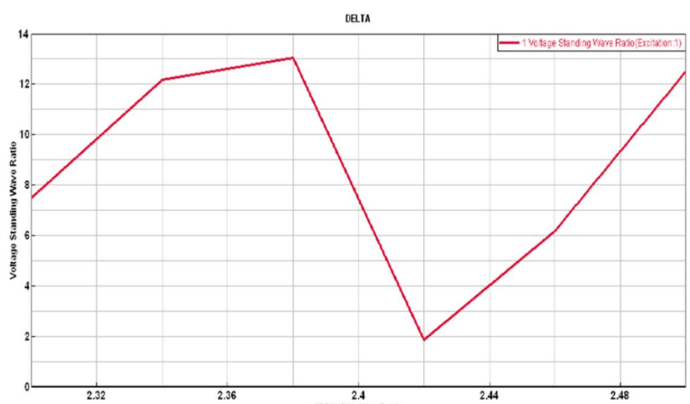

Fig. 5 VSWR of Triangular Patch Antenna which attains suitable value at 2.42 GHz

C. Return Loss

Return Loss or reflection coefficient is a measure which indicates how much power is reflected from the antenna back to the transmission line which indicates a loss in power transmitted. Hence, the return loss as minimum as possible. This can be achieved by properly impedance matching the antenna to the transmission line. From Fig. 6 we can tell that the return loss dips very low at the resonant frequency of 2.42GHz.This indicates that antenna radiates efficiently at 2.42 GHz. This is in turn helps to reduce VSWR to a considerable or sufficient value.

D. Gain

Gain of antenna is the ratio of maximum power propagated specifically directed in peak power radiation to that of an isotropic radiator. In the Fig. 7 shown below the maximum gain is encountered at the highest point of the radiation pattern and this is efficient for us because the antenna used for airborne application is supposed to be highly directive and maximum power should be transferred only in that direction.

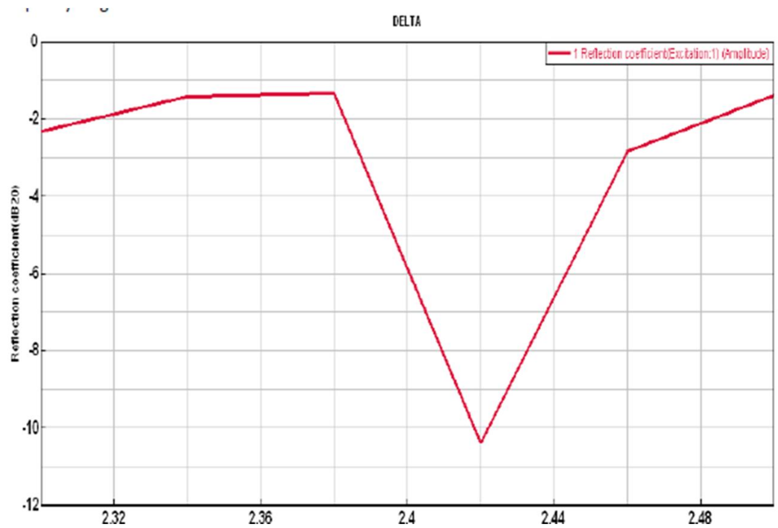

Fig. 6 Return loss of Triangular Patch Antenna

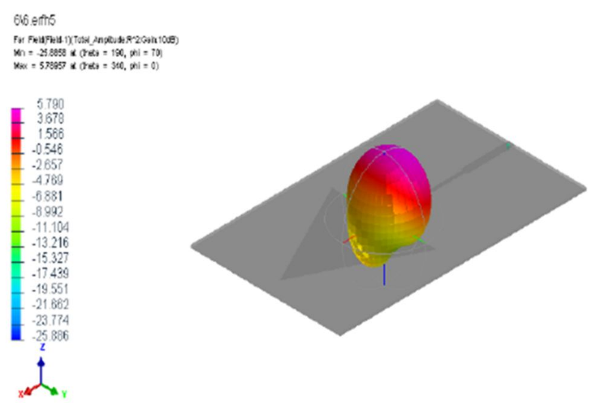

Fig. 7 Gain of Triangular Patch Antenna

VI. PRACTICAL TEST RESULTS

For testing purposes two antennas were fabricated according to specifications and were setup. The setup consists of Voltage Controlled Oscillator, a Detector and a Cathode Ray Oscilloscope. One antenna acts as transmitter connected to the VCO and the other acts as a receiver and is connected to the detector which is connected to the CRO. The receiving antenna is rotated in either clockwise or anti-clockwise direction and is placed at three different distances in front of the antenna. This is done to determine the radiation characteristics and receiving power of the antenna. The value of voltage at the receiving antenna at every angle it is rotated is recorded on the CRO and the power is calculated with respect to the voltage which is recorded when both antennas are facing each other and maximum radiation is transferred. The power is calculated with the formula-

$$P\ (dB) = 20 \log_{10}(V_o/V_i) \qquad (5)$$

Where, V_o is the maximum voltage received by the receiving antenna; V_i is the voltage at different angles with respect to the zero degree angle between transmitting and receiving antenna.
The polar plots obtained from plotting the points recorded show that for near field the maximum power obtained is higher.
The graphs for each power value at each corresponding value have been plotted and shown in Figs. 8, 9 and 10. For the near field the back lobe is more pronounced but for the mid-field and far-field the back lobe is less pronounced. Distortion occurs in the graph after 180 degree angle as after that angle reflections occur and the receiving antenna experiences radiation from different directions and hence the radiation from the transmitting antenna gets distorted.

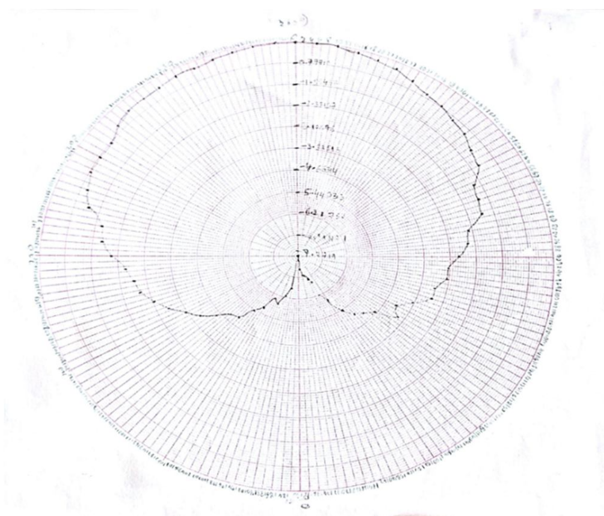

Fig. 8 Practical plot for near field radiation pattern

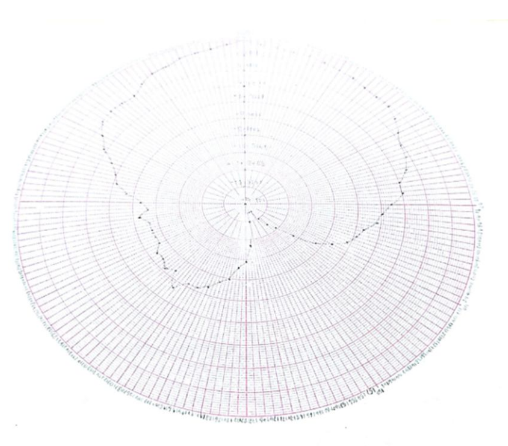

Fig. 9 Practical plot for mid field radiation pattern

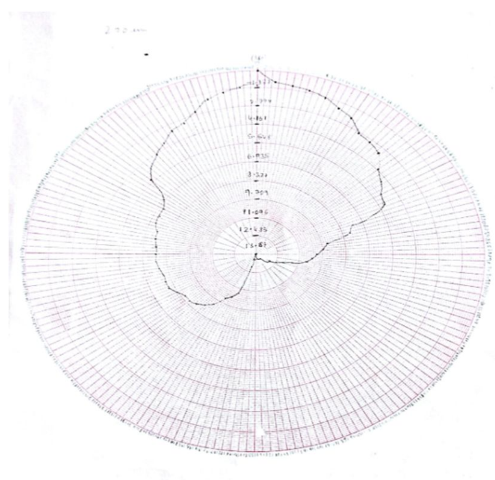

Fig. 10 Practical plot for far field radiation pattern

A. Radiation Patterns

The radiation patterns obtained are for three regions namely-near field, mid-field, and far-field. A comparison between radiation patterns of each region are made at the end of the section as shown in shown in Figs 11,12 and 13.

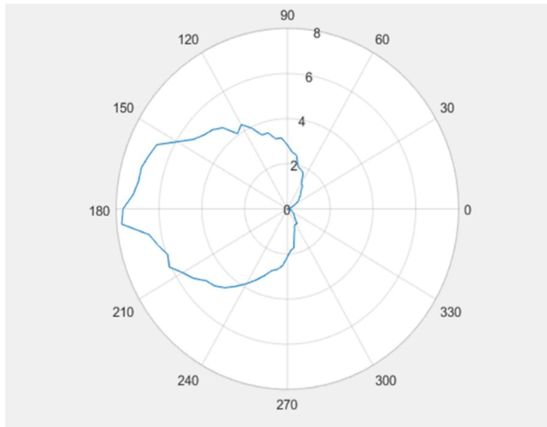

Fig.11 Field patterns of TM_{10} mode for f_r = 2.4GHz; $\mathcal{E}_r$ = 3.2,h = 0.79mm for near-field region

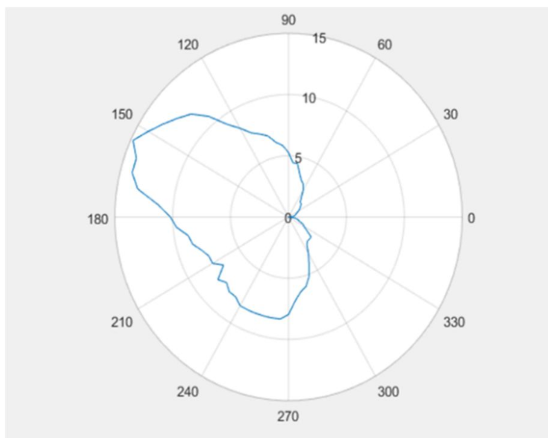

Fig.12 Field patterns of TM_{10} mode for f_r = 2.4GHz; $\mathcal{E}_r$ = 3.2,h = 0.79mm for mid-field region

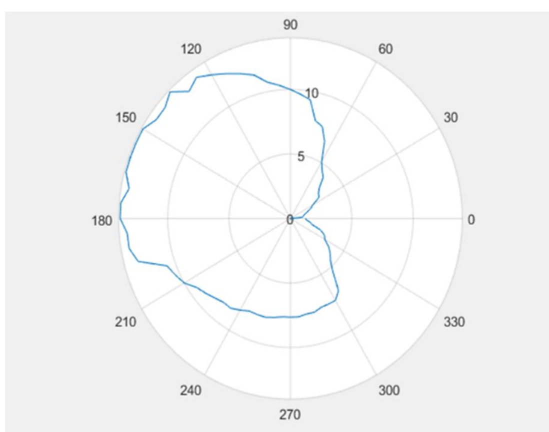

Fig.13 Field patterns of TM_{10} mode for f_r = 2.4GHz; $\mathcal{E}_r$ = 3.2,h = 0.79mm for far-field region

The radiation patterns have been plotted using MATLAB simulation software and shown in Figs 12,13 and 14. For the TM_{10} mode, in the near-field region the broadside pattern is more directional as compared to the mid-field and far-field regions. The results that we have obtained after making several observations are being presented here. Testing antenna height, radiation pattern, return loss & gain measurements have given us insight on how to develop a suitable antenna for our needs and requirement for our project. This in turn helped to make adjustments to our previous assumptions.

VII. Conclusion

While designing the antenna using software, we have observed the radiation pattern which is hemispherical in shape spread equally in all directions. But when it comes to reality, due to practical considerations, the radiation pattern is limited to a particular direction only. In this way, we can even design triangular patch antenna and generate radiation pattern. In obtaining the results of radar system, we can track the object within the specific region but we cannot come to a conclusion that the results obtained are accurate. Hence, we started design a radar system to capture large distances and obtain accurate results. While observing the simulation results of triangular patch antenna, we found a dip when the frequency is at 2.4GHz which signifies the output is proper and steps followed in the design of antenna is correct. Also, we have plotted different graphs on gain, input impedance and other parameters to verify our results on CEM solutions software. During the testing of fabricated triangular patch antenna, we have successfully calculated the power received by the receiver antenna by rotating it by 360 degrees in steps of 5 degrees [7]. We have observed the voltage values on the oscilloscope with the help of detector .we have calculated the gain for each voltage levels which have been attached in the excel sheets in this report. Using these values of gain measurements, we have plotted polar plots both manually and MATLAB simulations for near field and far field patterns.by comparing both the graphs obtained, we obtained almost similar patterns. This also signifies that the antenna dimensions which have been calculated are accurate.

There is a wide range of scope in this project in the development of radar system. Simulation of UAV-UGV strategy algorithm-motion synchronization and sensor fusion can be done in the system [6]. In this, when we mount our radar to UAV and test it, we can capture objects while they are moving. This allows us to improve the detection of moving objects effectively. Further, Anti-drone activity to avoid the threats could be successfully implemented. If there are any possible threats near its range, they are successfully detected and sends the information to the ground station. The expansive growth in the demand for wireless communication and information transfer using handsets has created a need for major advancements in design of antennas as a fundamental part of any wireless system where different constraints should be taken care. The micro-strip antennas, due to their great advantages, have lot of applications in wireless communication systems. Handheld devices and satellite systems require antenna with precise qualities as per application.

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