Report regarding Radio Frequency Radiation from Camera Back Wireless Transmitters in the Film and Television Production Environment

Prepared for:

The International Cinematographers Guild

By:

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I. BACKGROUND

A Wireless video camera is an important tool for the cinematographer working in the Film and Television production environment. The wireless camera represents the ultimate in mobility, providing high-quality high-definition video transmission in the most challenging environments. The wireless camera is vital to content generation, especially for live television including sports, awards shows, and breaking news. Advances in micro-electronics, digital signal processing, receiver technology, and market competition have led to wireless video transmitters with high-performance, high-reliability, small size, and lower prices.

Today's High-Definition (HD) wireless cameras transmit digital data using radio frequency (RF) spectrum which is regulated by the Federal Communications Commission (FCC) in the United States. These transmitters typically operate in the 2.4 GHz and 5.8 GHz license free Industrial, Scientific, and Medical (ISM) spectrum defined by the FCC in the Code of Federal Regulations Title 47, Part 15. Part 15 devices are limited in power (and range), however, they require no special license to operate. The only requirement under Part 15 is that the equipment must be properly certified (FCC Type Certified) as compliant with the technical requirements of the FCC for intentional radiators. When greater range is required for a particular application (higher transmitter power), a Special Temporary Authorization (STA) may be obtained from the FCC for limited use in frequencies outside the ISM Part 15 frequency band.

In addition to regulations relating to the use of the RF spectrum, the FCC also has guidelines regarding RF safety. RF safety is the focus of this report. The FCC guidelines regarding RF safety are designed to protect the general public from unhealthy levels of Radio Frequency Radiation (RFR). These rules apply to all devices which radiate RF energy including radio and television broadcast transmitters, cellular telephones, taxi cab two-way radios, FRS radios, and camera back wireless video transmitters. The rules specify a safe level of exposure to protect human health.

The International Cinematographers Guild contracted to Full Motion Video (FMV) to examine the way in which wireless video transmitters are used in the Film and Television production environment to determine if Cinematographers could be subjected to unhealthy levels of RFR. This report describes that effort and presents the results of the study.

II. RF SAFETY

In August of 1997, the FCC Office of Engineering & Technology (FCC OET) issued Bulletin 65 Edition 97-01 – Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields. This bulletin is an update of the FCC's OST Bulletin 65, originally issued in 1985. Manufacturers of wireless transmission products which are regulated by the FCC, are required to provide a statement regarding RFR safety as part of the FCC equipment approval process. This applies to all transmitters, including the unlicensed equipment used under FCC Part 15. The RFR safety statement provides advice to the user of the equipment on how to comply with the FCC's RF exposure safety limits, and, subsequently, safely operate the equipment. This statement is found in the Operating Manual of the wireless product. Bulletin 65 provides the technical information necessary for the manufacturer to determine the safe operating limits of the equipment.

Subsequently, in August of 1999, the FCC OET issued Bulletin 56 Fourth Edition – Questions and Answers about Biological Effects and Potential Hazards of Radio Frequency Electromagnetic Fields. This bulletin addresses concerns regarding the risks to human health from environmental RF electromagnetic fields. Bulletin 56 states that high levels of non-ionizing RF energy can cause tissue heating in humans (thermal effect). It is important to note that the type of radiation that is emitted from camera back wireless transmitters is known as "non-ionizing" radiation. The type of radiation emitted from X-rays and gamma-rays is known as "ionizing" radiation and this type of energy is not emitted by devices used for RF telecommunications applications.

> From OET 56 - *The FCC's policies with respect to environmental RF fields are designed to ensure that FCC-regulated transmitters do not expose the public or workers to levels of RF radiation that are considered by expert organizations to be potentially harmful. Therefore, if a transmitter and its associated antenna are regulated by the FCC, they must comply with provisions of the FCC's rules regarding human exposure to RF radiation. In its 1997 Order, the FCC adopted a provision that all transmitters regulated by the FCC, regardless of whether they are excluded from routine evaluation, are expected to be in compliance with the new guidelines on RF exposure by September 1, 2000.*

Study of the effects of biological effects from RFR are on-going and policies and regulations are updated as necessary as the result of appropriate and scientifically valid research.

> From OET 56 - *In 1996, the World Health Organization (WHO) established a program (the International EMF Project) designed to review the scientific literature concerning biological effects of electromagnetic fields, identify gaps in knowledge about such effects, recommend research needs, and work towards international resolution of health concerns over the use of RF technology. The WHO and other organizations maintain Internet Web sites that contain additional information about their programs and about RF biological effects and research. The FDA, the EPA and other federal agencies responsible for public health and safety are working with the WHO and other organizations to monitor developments and identify research needs related to RF biological effects.*

Our concern in this study is the heating of human tissue (the cinematographer) as a result of exposure to the RF field from a typical camera back wireless transmitter. The potential for excessive exposure (Maximum Permissible Exposure or MPE) is bounded by a number of conditions:

1. The intensity of the RF field (power density) produced by the RF device
    a. RF power output
    b. Antenna gain
    c. Distance from the antenna
2. The frequency of operation of the RF device
3. The duration of the exposure to the RF field
4. The environment (controlled or uncontrolled)

RF power density is expressed as the amount of RF energy in a given area in mW/cm^2. 1 mW equals 0.001 Watts. The MPE limit for Occupational/Controlled exposure is 5 mW/cm^2 for frequencies from 1.5 GHz to 100 GHz. This is the frequency band in which most camera back wireless transmitters operate.

- Because of the limitations imposed by the regulations found in FCC Part 15, most camera back wireless transmitters operate with an RF power output level of around 200 mW (0.2 W). Consider that the RF power output level of a typical handheld UHF voice transceiver is around 4 W (or 20 times more power).
- Power density is effected by antenna gain. Antenna gain is the increase in energy level in a particular direction as a result of the design of the antenna. For example, a certain type of antenna may put more energy on the horizon (in the direction of the cinematographer operating the camera) while another antenna may put more energy toward the sky. Antennas are selected for their “pattern” as required by the application. In most cases, omni-directional antennas are used on camera back wireless transmitters with a gain of 3 – 5 dBi. Since antenna gain impacts the range performance of a Part 15 transmitter, the power level must be adjusted accordingly to maintain FCC compliance. Therefore, an antenna with more gain will result in the reduction of RF power to maintain the same RF power density at a particular distance. The operating manual of the FCC Certified transmitter provides information on how to set transmitter power for a particular antenna.
- The closer the operator is to the radiating source, the greater the power density will be. For each doubling of the distance from the transmitting source, the power density is reduced by 4 times. The strength of the power density is increased when the transmitter power output level is increased.
- The FCC guidelines specify different MPE levels for different frequency ranges. This variation is due to the way in which the human body absorbs RF energy at different wavelengths. For example, for frequencies in the VHF range (30 – 300 MHz), the maximum power density is only 1 mW/cm^2. This is a decrease of over 4 times the power density allowed for the 1.5 – 100 GHz frequency band. Some wireless microphones used in the Film and Television production environment operate in the VHF range.
- Exposure to an RF field is averaged over time to arrive at the Maximum Permissible Exposure limit. The averaging time for exposure in the frequency range of 1.5 – 100 GHz is 6 minutes. This means that the cinematographer can be exposed to the maximum power density of 5 mW/cm^2 for a total of 6 minutes until the MPE limit is reached. Since this is based on averaging, the operator can be exposed to a field of 2.5 mW/cm^2 for a period of 12 minutes until the MPE limit is reached. Also, if the power density was 10 mW/cm^2, the operator could only be exposed to the field for 3 minutes. The remaining 3

minutes of the 6 minute exposure window must have no further exposure to the RF field.

- The FCC guidelines define two types of environments with regard to RFR exposure:
    - The Occupational/Controlled Environment - *For FCC purposes, applies to human exposure to RF fields when persons are exposed as a consequence of their employment and in which those persons who are exposed have been made fully aware of the potential for exposure and can exercise control over their exposure. Occupational/controlled exposure limits also apply where exposure is of a transient nature as a result of incidental passage through a location where exposure levels may be above general population/uncontrolled limits (see definition above), as long as the exposed person has been made fully aware of the potential for exposure and can exercise control over his or her exposure by leaving the area or by some other appropriate means.* On the set, the cinematographer would be considered to be in an Occupational/Controlled environment. The MPE for the Controlled environment is 5 mW/cm^2 in the frequency range of 1.5 – 100 GHz.
    - The General Population/Uncontrolled Environment - *For FCC purposes, applies to human exposure to RF fields when the general public is exposed or in which persons who are exposed as a consequence of their employment may not be made fully aware of the potential for exposure or cannot exercise control over their exposure. Therefore, members of the general public always fall under this category when exposure is not employment-related.* On the set, other trades not familiar with the existence of a camera back wireless transmitter would be considered to be in the General Population/Uncontrolled environment. The MPE for the Uncontrolled environment is 1 mW/cm^2 in the frequency range of 1.5 – 100 GHz. This is over 4 times more restrictive than the MPE for the Controlled Environment.

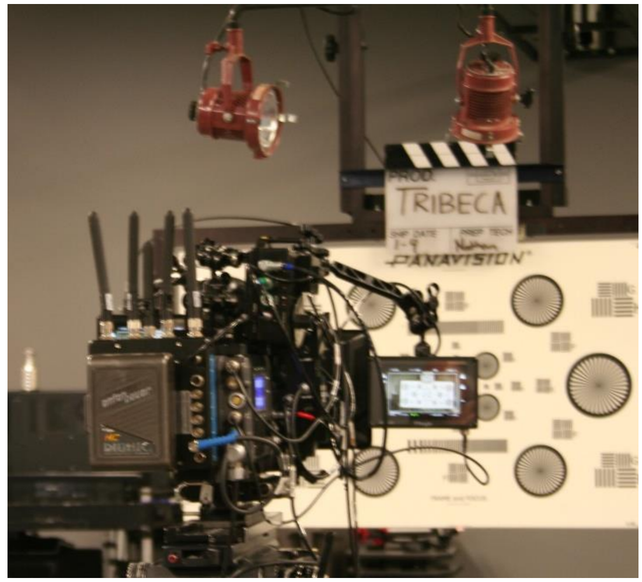
Taking in consideration all of the factors which influence the Maximum Permissible Exposure, we can draw the conclusion that the best solution to RF exposure in the Film and Television production environment is to maintain a condition that is “unconditionally compliant”. In other words, when this condition exists, the cinematographer or members of the public will not be exposed to fields which exceed the MPE.

Many of the variables above are easy to control. For example, the power output of the camera back wireless transmitter operating under FCC Part 15 is limited by regulation. While the antenna gain may be varied by the user, FCC regulations mandate that the power of the transmitter be adjusted accordingly so as not to increase the radiated power density beyond the allowable radiated limit. The frequency of operation of the transmitter is known and falls within the range of 1.5 – 100 GHz which prescribes an MPE of 5 mW/cm^2 for the Controlled environment and 1 mW/cm^2 in the Uncontrolled environment averaged over a 6 minute period.

The goal is to insure that the MPE is never exceeded in either the Controlled or Uncontrolled environment under normal operating conditions. The remaining variable is the distance of the operator from the antenna. If we define a worst case operating condition (maximum allowed radiated power output) we can mathematically determine a minimum safe distance from the antenna which will never exceed the MPE and provide an “unconditionally compliant” environment.

III. DATA COLLECTION

In order to understand the types of camera back wireless equipment, and the operational modes of the wireless camera, Full Motion Video made two field trips. One trip was to Panavision, a hardware systems integrator and equipment provider to observe the types of mounting systems, antennas, and range of transmitters provided to their customers. The other trip was to Golden Oak Ranch to observe the interaction between the wireless system and the cinematographer in the typical workflow. At both Panavision and Golden Oak Ranch, FMV took field intensity measurements of the systems operating at both 2.4 and 5.8 GHz.



Multi-Channel TDMA Camera Back Wireless Video Transmitter at Panavision.

All observed systems operated in the FCC Part 15 non-licensed band and had the proper FCC identification plaque affixed to the transmitter. All of the transmission technology observed was High-Definition digital transmission using either multi-channel WiFi type Time Division Multiple Access (TDMA) transmission or industry standard Coded Orthogonal Frequency Division Multiplex (COFDM). No effort was made to assess the quality of the video transmitted through the links.

COFDM Camera Back Wireless Video Transmitter at Golden Oak Ranch.

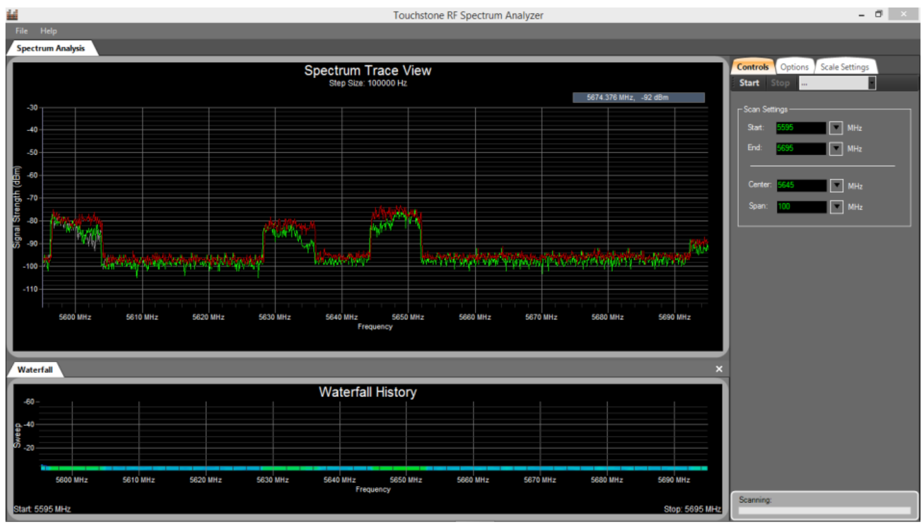
Wireless camera systems using multiple simultaneous transmission channels have the same aggregate transmission power of a single transmitter COFDM type system, therefore each individual transmitter puts out less power. Regardless of the number of transmitters in the system, the radiated power output is the same and the “unconditionally compliant” distance is constant between the technologies.

The maximum allowable transmitter output power in the Part 15 frequency bands is 1W. However, due to the special design requirements for digital transmission systems, transmitter power output is usually on the order of 1/4W or 0.250 mW. The actual RF power output level of any FCC Certified transmitter can be determined by examination of the FCC records for that product (listed under the FCC ID number) or through measurement on the

Field intensity measurement of COFDM Camera Back Wireless Video Transmitter at Golden Oak Ranch.

test bench. It is important that the operator always verifies that the equipment in use has the proper FCC Certification label on the equipment itself since this compliance is critical to the baseline assumptions associated with the safety calculations.

At each location, field intensity measurements were taken of the operational hardware using commercially available RF safety measuring equipment. This equipment is designed to warn personnel of high RF fields over a wide frequency range which could cause a violation of the MPE. While the equipment is useful in a variety of industrial RF safety applications, it is not well suited for the relatively low power output of the typical camera back wireless transmitter operating in the 2.4 GHz and 5.8 GHz range.



RF spectral plot showing four different COFDM wireless transmitters operating simultaneously at Golden Oak Ranch.

On a set with multiple RF emitters, including camera back transmitters, wireless microphones, two-way radios, wireless LAN's, and other unknown transmitters, this equipment could be useful for taking a "look" at the total RF environment from a safety standpoint. This is especially true of environments which are beyond the control of the producer or production company.

The spectrum analyzer was used at Golden Oak Ranch to survey the RF environment in the 5.8 GHz band. The plot to the right shows four different transmitters operating simultaneously. There is the signature of a COFDM transmitter (known as Bart's head) on the display at either extreme as well as two near the center. The spectrum analyzer is useful as an analytic tool to determine the frequency and relative power level of RF sources in the environment. The frequency of the transmitter can be determined by noting the position of the signal along the x-axis (left to right) and the relative strength of the signal can be determined by noting the position of the top of the signal along the y-axis (top to bottom). The spectrum analyzer can be used to quickly assess if a transmitter system is operating within its FCC certified parameters by checking frequency and power level. It is also a useful tool for interference detection and mitigation on the set. It is important to note that all transmitters in the environment contribute to the MPE level.

In addition to taking field intensity and spectral measurements at Golden Oak Ranch, FMV observed and measured the particulars of the workflow of the cinematographer operating a wireless camera. Of particular note was the distance between the transmitting antenna and the operator for different shot styles as well as the duration of the camera operation. These are two important parameters which relate to the MPE value.

The shoulder shot provides the greatest separation between the transmitting antenna and the cinematographer.

Three common shot positions were evaluated at Golden Oak Ranch. The shoulder shot, the hip shot, and the kneeling shot. The dynamics with respect to the position of the transmitting antenna were the same for the hip shot and the kneeling shot. The shoulder shot provided the best separation between the transmitter and the cinematographer.

The shoulder shot provides approximately 8 inches (20 cm) of separation while the hip and kneeling shots provide approximately 3 inches (7.5 cm) of separation between the antenna and the cinematographer.

The hip and kneeling shot minimizes the separation between the transmitting antenna and the cinematographer.

As noted above, the MPE limits are based upon an average exposure interval of 6 minutes. The cinematographer at Golden Oak Ranch indicated that it is not uncommon to operate the wireless camera system using a variety of shot techniques for periods of up to 2.5 hours continuously. Clearly, this type of workflow is incompatible with the RF safety guidelines assuming that the operator is exposed to the MPE power density limit for the Controlled environment of 5 mW/cm^2.

In order for the typical camera back wireless transmitter system to be useful in this type of production environment, the cinematographer must not reach the MPE limit for the entire duration of the camera operation. This is why “unconditional compliance” is key to RF safety in the Film and Television production environment.

IV. DATA ANALYSIS

While test instrumentation was used to acquire data at both Panavision and Golden Oak Ranch, the most reliable and repeatable way to analyze the RFR field from a wireless device certified under FCC Part 15 is the use the data supplied by the manufacturer as part of the certification filing. This method eliminates the variability associated with field measurements where equipment may become uncalibrated, operated incorrectly, subject to other unknown RF fields, or not properly placed in the aperture of the transmitting antenna. As noted above, portable RF field intensity equipment is very useful for determining the "big picture" as it relates to the RF environment on a set. However, since test measurements submitted to the FCC for equipment certification are made under controlled laboratory conditions, using laboratory grade test equipment with traceable calibration and operated by trained technicians, making this the best data for analysis.

BMS COFDM transmitter with FCC ID: VFB-NT5723SDHD5G8 at Golden Oak Ranch, S/N B2048.

In order to make a mathematical analysis of the data there must be some assumptions:

1. The equipment has not been modified in any way that would change the characteristics associated with FCC Part 15 Equipment Certification.
2. The equipment is in good working order.
3. The proper antenna is affixed to the transmitter and the RF power level is set appropriately for the antenna gain as per the manufacturer's recommendation.
4. There is no external equipment (RF amplifier) connected to the transmitter that would increase the strength of the RF signal.

5.8 GHz 3 dBi Gain Omni-directional Antenna

For this analysis, we will use the transmitter from the Golden Oak Ranch as the baseline.

This transmitter operates in the unlicensed 5.8 GHz band and is FCC Certified under Part 15 as an intentional radiator. According to Broadcast Microwave Services (BMS), this transmitter has a nominal

RF power output of 200 mW (0.200 W). The antenna in use with the transmitter is an omni-directional antenna with a published gain of +3 dBi.

The antenna is mounted on a short mast to raise it just above the top of the camera housing. The transmitter is powered by an industry standard clip-on rechargeable battery.

In the FCC OET 65 document, a mathematical formula is provided to calculate the power density of the transmission system at a given distance. The following data must be known in order to make this calculation:

1. Effective Radiated Power (a combination of the transmitter RF output power and the antenna gain).
2. Controlled or Uncontrolled Environment (power density in mW/cm^2).

Rearranging the terms of the equation, we can solve for the distance between the transmitter antenna and the operator at the MPE level for both Controlled (Pd = 5) and Uncontrolled (Pd = 1) environments.

$$r = \sqrt{\frac{EIRPmW}{4\pi \bullet Pd}}$$

Where:
r = safe distance in cm
EIRPmW = Transmitter power (dBm) + antenna gain (dBi)
Pd= Power density in mW/cm^2 (1 or 5)

According to BMS, the test data record for S/N: B2048 shows a transmitter RF power output of 200 mW. In order to add the antenna gain to get the Effective Radiated Power, we must convert power in mW to power in dB. 200 mW = 23 dBm. Transmitter RF power (23) + antenna gain (3) = 26. Converting back to mW- 26 dBm = 400 mW. **EIRPmW = 400**.

Solving for the Controlled environment (Pd = 5), the equation becomes:

$$r = \sqrt{\frac{400}{4\pi \bullet 5.0}}$$

Where:
r = 2.5 cm (0.98 in)
EIRPmW = +26 dBm (23 + 3) = 400 mW
Pd= Power density 5 mW/cm^2

This calculation shows that the MPE of 5 wW/cm^2 occurs at a distance of 2.5 cm (0.98 in.) from the antenna for our test case. Therefore, at a distance greater than 2.5 cm from the antenna, the operator can never exceed the allowed MPE. **Any distance greater that 2.5 cm from the antenna under Controlled conditions is <u>Unconditionally Compliant</u> with the FCC RFR Exposure Guidelines.**

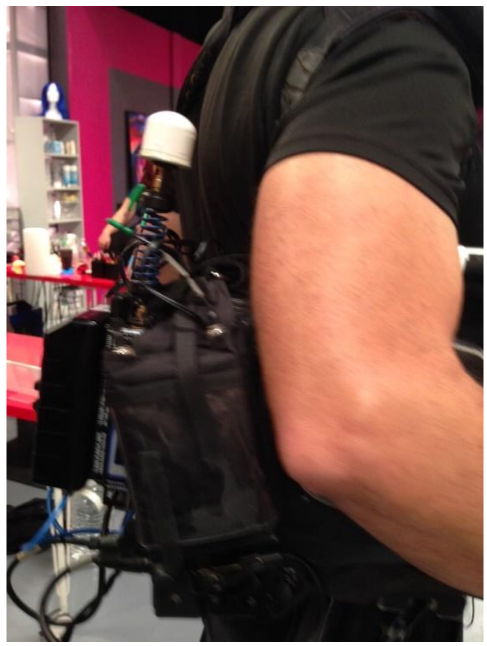
Let's solve the equation for the Uncontrolled (Pd =1) environment in which others on the set may find themselves.

$$r = \sqrt{\frac{400}{4\pi \bullet 1.0}}$$

Where:
r = 5.6 cm (2.2 in)
EIRPmW = +26 dBm (23 + 3) = 400 mW
Pd= Power density 1 mW/cm^2

This calculation shows that the MPE of 1 wW/cm^2 occurs at a distance of 5.6 cm (2.2 in.) from the antenna for our test case. Therefore, at a distance greater than 5.6 cm from the antenna, the operator can never exceed the allowed MPE. **Any distance greater that 5.6 cm from the antenna under Uncontrolled conditions is Unconditionally Compliant with the FCC RFR Exposure Guidelines.**

Now, let's examine a case where the "unconditionally compliant" safe distance cannot be realized in the workflow due to the nature of the requirements for the particular shot. This image shows the same transmitter and antenna being used with a special hip-shot rig which places the antenna directly against the back of the cinematographer. Clearly, the antenna is closer than 2.5 cm in this configuration. We can calculate the field intensity that the operator is subjected to assuming a transmitter power output of 0.2 W, and an antenna gain of 3 dBi. If we assume that the radiating element of the antenna is located directly in the center of the white radome, we will use a value of 1.3 cm (0.5 in.) for the distance between the antenna and the operator.



5.8 GHz 3 dBi Gain Omni-directional Antenna directly against the back of the Cinematographer

$$\text{Power Density} = \frac{EIRP}{4\pi R^2}$$

Where:
r = 1.4 cm (0.5 in)
EIRPmW = +26 dBm (23 + 3) = 400 mW
Power density = 16 mW/cm^2

In this case, the Cinematographer is subjected to a field intensity of 16 mW/cm^2 during the camera operation. Since the maximum MPE for the controlled environment is a field intensity of 5 mW/cm^2 averaged over a period of 6 minutes, it is clear that a mitigation technique is necessary to comply with the FCC safety guidelines. If it is not possible to reconfigure the camera back transmitter in such a way that the antenna can be at a distance greater than 0.98 inches (the safe distance for this transmitter/antenna combination) then the exposure time must be limited.

The MPE limits set forth in the FCC guidelines allow for a maximum exposure to a field intensity of 5 wW/cm^2 for a duration of 6 minutes. Since the calculated field is approximately 3 times greater than the MPE limit, we can divide the exposure time by 3 to arrive at a new maximum exposure duration of 2 minutes. After this two minute operational period, the operator must shut the transmitter off and wait for six minutes before operating for the next two minute cycle in order to be in compliance with the FCC RFR exposure guidelines. This cycle can continue on and on until the shooting is finished if the antenna must remain in this position.

The calculations for the test (typical) transmitter used at Golden Oak Ranch indicate safe distances which are easy to maintain with most workflows. FCC Title 47, Part 15, Section 15.247 (3) allows for digitally modulated transmitters operating in the 2400 – 2483.5 MHz and 5725 – 5850 MHz bands a maximum allowable RF power output of 1W (+30 dBm). If we assume this 1W power output level as "worst case" we can calculate an "Unconditionally Compliant" safe distance for any camera back wireless transmitter operating in these frequency ranges.

Solving for the worst case Controlled (Pd = 5) environment, the equation becomes:

$$r = \sqrt{\frac{2000}{4\pi \bullet 5.0}}$$

Where:
r = 5.6 cm (2.2 in)
EIRPmW = +33 dBm (30 + 3) = 2000 mW
Pd= Power density 5 mW/cm^2

This calculation shows that the MPE of 5 wW/cm^2 occurs at a distance of 5.6 cm (2.2 in.) from the antenna for our worst case. Therefore, at a distance greater than 5.6 cm from the antenna, the operator can never exceed the allowed MPE. **Any distance greater that 5.6 cm from the antenna under Controlled conditions is Unconditionally Compliant with the FCC RFR Exposure Guidelines for a worst case transmitter.**

Solving for the worst case Unontrolled (Pd = 1) environment, the equation becomes:

$$r = \sqrt{\frac{2000}{4\pi \bullet 1.0}}$$

Where:
r = 12.6 cm (5 in)
EIRPmW = +33 dBm (30 + 3) = 2000 mW
Pd= Power density 1 mW/cm^2

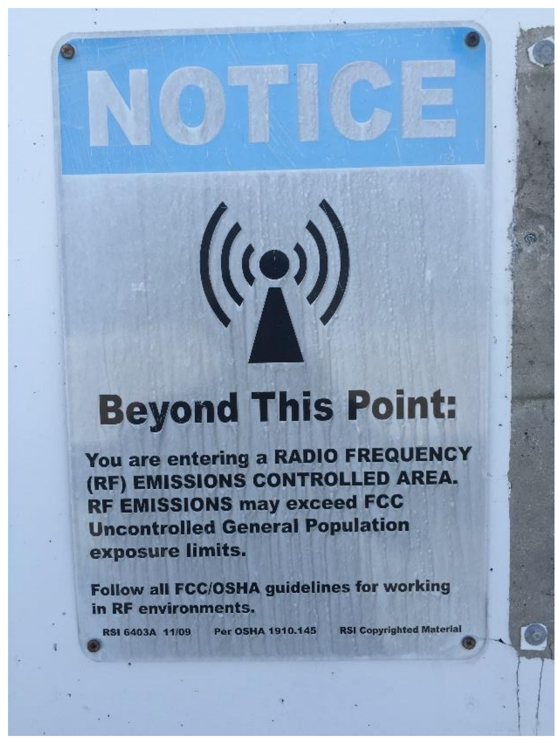
This calculation shows that the MPE of 1 wW/cm^2 occurs at a distance of 12.6 cm (5 in.) from the antenna for our worst case. Therefore, at a distance greater than 12.6 cm from the antenna, the operator can never exceed the allowed MPE. **Any distance greater that 12.6 cm from the antenna under Uncontrolled conditions is Unconditionally Compliant with the FCC RFR Exposure Guidelines for a worst case transmitter.**

V. CONCLUSIONS AND RECOMMENDATIONS

This study was designed to survey the typical workflow of the cinematographer using a wireless camera back video transmitter in the Film and Television production environment and compare that workflow against the FCC's radio frequency radiation safety requirements to determine how to identify and mitigate potential health hazards to the ICG member.

A variety of camera system types, technologies, and integrations were examined at the Panavision facility in Woodland Hills, CA to understand how the hardware was utilized and installed on the camera system. In addition, actual production workflow was studied at the Golden Oak Ranch during the production of a reality television show which utilized a number of wireless camera back video transmitters. Data was gather during each site visit and analyzed later against the regulatory framework established by the FCC with respect to wireless equipment authorizations and the requirements for human exposure to non-ionizing radiation.

The FCC guidelines for human exposure to radio frequency electromagnetic fields address the health effects of RFR and specify how long a human can be exposed to an RF field in a particular frequency range before health concerns arise. This limit is known as the maximum permissible exposure or MPE. The MPE level is different for controlled and uncontrolled exposure levels. The controlled environment is one in which someone is aware of the potential hazard of over exposure to RFR and has the ability to control or limit the exposure to safe levels. The uncontrolled environment typically represents the general public space where knowledge of the RFR exposure is not readily available. The MPE limit for the uncontrolled environment is significantly more restrictive than the controlled environment. The workflow of the cinematographer would be considered to take place in the controlled environment, while the exposure to RFR from a camera back wireless video transmitter on the set by other crew members would be considered to fall into the uncontrolled environment.



RF Hazard sign located at the antenna site atop the Vehicle Assembly Building (VAB) at the Kennedy Space Center in Florida.

The key to RFR safety in the Film and Television production environment is identification and mitigation of the potential RF hazard. Knowing that radio frequency energy is being transmitted on the set and knowing how to maintain safety around the transmitters can minimize exposure to unsafe levels of radio frequency radiation.

One mitigation technique is to fully understand the location and intensity of an RF field and modulate the time of exposure to that field according to the FCC guidelines. While this may be practical in some technical activities, it is not likely to work well in the highly dynamic environment associated with Film and Television production. The simplest and most effective approach to RFR exposure is to avoid exposure at the MPE level under all conditions.

The "unconditionally compliant" condition exists for every transmitter because RF fields reduce in energy as the distance from the antenna is increased. In fact, the energy level is reduced by 4 times when the distance is doubled. So, at some distance from the antenna, the RF field is so weak that it no longer has the potential to effect human health even though it is strong enough to provide adequate signal to a nearby wireless receiver. For example, at the Mt. Wilson transmitter site for K-EARTH 101, there exists some space where the signal level is high enough to reach the MPE, however, no health hazard exists from the radio station along the 405 even though the signal is strong enough to provide excellent mobile coverage.

The majority of wireless camera back video transmitters used in the Film and Television production environment are regulated by the FCC under Part 15 as an intentional radiator. Part 15 requires no FCC license and Part 15 devices operate in shared spectrum using low power levels. Because the transmitted power levels of these Part 15 devices is low, the power density which represents the MPE level is confined in the area close to the antenna. Therefore, it is possible to be "unconditionally compliant" with the MPE level by maintaining a certain distance from the antenna at all times.

To establish the "unconditionally compliant" condition, we should assume the worst case RFR exposure scenario. In this way, we can satisfy the MPE limit for both the controlled and uncontrolled environments. The FCC Part 15 frequency bands where most wireless camera back transmitters are certified are the 2.4 GHz and 5.8 GHz bands. The MPE for both of these frequency bands is the same power density. So, we only need to solve for the stricter of the two environments: the uncontrolled environment. Additionally, since the Part 15 rules allow for certified transmitters with a power level up to 1W, we will use this maximum power level in our calculations. The fact that most transmitters operate at an RF power level ¼ of the maximum allowed (0.25W) simply provides extra safety margin in the real world operating environment.

Applying these conditions to the formula above, we find that the "unconditionally compliant" condition exists at a distance of 5 in. from the transmitting antenna. This distance is safe for all certified wireless camera back video transmitters operating under FCC Part 15 in the 2.4 GHz and 5.8 GHz frequency bands. This means that as long as a distance of at least 5 in. from the transmitting antenna is maintained, it is not possible to exceed the MPE limits set forth by the FCC.

In light of the data analysis, the following recommendations are made to help maintain RF safety in the Film and Television production environment:

1. All wireless camera back video transmitters must be FCC certified for Part 15 and comply with the following:
    a. The transmitter has a legible FCC ID number on the manufacturer's product tag affixed to the unit.
    b. The transmitter has not been modified in any way from its original state as delivered by the manufacturer.
    c. All transmitter cabling is in good condition and properly attached.
2. The operator should have a clear understanding of the requirements for operating the equipment to maintain unconditional compliance with the MPE limits for both controlled and uncontrolled environments.
3. The operator should review the RF Safety Statement provided by the manufacturer for the particular transmitter prior to operation of the transmitter.

4. When the "unconditionally compliant" condition cannot be met, the operator should mitigate the exposure danger by observing the time limit for RFR exposure so as not to exceed the MPE.
5. When a wireless video transmitter is used that is not certified under FCC Part 15 and requires a Special Temporary Authorization (STA) from the FCC, the operator should understand the potential for RFR exposure and take precautions to not exceed the MPE during the course of work. (Such equipment is typically used for long-range shots and uses high-powered transmitters and high-gain directional antennas.)
6. The operator should be aware of the RF environment to understand what other transmitters may contribute to the total exposure to RFR.
7. Cinematographers should receive specialized training regarding the identification and mitigation of RF Safety issues in the workplace.

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