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Spectrum for Digital Radio Cameras

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Abstract

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Programme makers are experimenting with using digital radio cameras where analogue radio cameras would not normally be considered, such as in television studios. This expansion of use comes at a time when the 2.5GHz band will soon be reallocated to 3G mobile telephony and so suitable alternative spectrum will be needed for digital radio cameras.

The technology behind digital radio cameras is outlined, concentrating on the design compromises that have an impact on spectrum usage. Future trends in the development of digital radio cameras by the broadcast industry are also discussed.

The various applications for digital radio cameras will be described indicating the numbers of cameras involved in order to indicate the spectrum requirements. Results from measurements carried out in collaboration with the RA and JFMG Ltd to assess the feasibility of sharing with unlicensed users in the 2.4GHz are outlined.

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SPECTRUM FOR DIGITAL RADIO CAMERAS

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INTRODUCTION

Digital radio cameras (wireless television cameras) are beginning to be used in the BBC for making a wide range of television programmes. They have the advantage over analogue radio cameras in that they have a greater immunity to multipath and interference. This ruggedness comes from the use of the DVB-T (Digital Video Broadcasting – Terrestrial) modulation standard developed for digital television. However, to maintain a high picture quality, while minimising video coding delay, a high bit rate is transmitted.

Programme makers are experimenting with using digital radio cameras where analogue radio cameras would not normally be considered, such as in television studios. This expansion of use comes at a time when the 2.5GHz band will soon be reallocated to 3G mobile telephony and so suitable alternative spectrum will be needed for digital radio cameras.

The technology behind digital radio cameras is outlined, concentrating on the design compromises that have an impact on spectrum usage. Future trends in the development of digital radio cameras by the broadcast industry are also discussed.

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RADIO CAMERAS

A radio camera is a television camera with a compact transmitter attached (Fig 1). Generally, when a television programme is made, the video signals from all the cameras being used are sent through cable to a control gallery (for studios) or to a 'scanner' vehicle (at an outside broadcast) so that the programme director can choose which pictures to include in the programme. In some situations it is difficult or impossible to use a cabled camera, for example a camera on a football touchline or a camera on a vehicle. A radio camera is the solution in such cases.

Fig. 1. BBC Digital Radio Camera

The most common radio camera operating band is 2.5 – 2.7 GHz. There are some smaller bands up to 12 GHz, but these must be shared with other types of video link, e.g. the link back to the studio. Channels are booked as needed from JFMG Ltd (Joint Frequency Management Group Ltd) on behalf of the RA (Radiocommunications Agency).

Transmission distances are typically a few hundred metres for handheld operation, e.g. in a sports stadium or newsgathering in the street, to a kilometre or so for a ground vehicle, e.g. horse racing. Airborne use may require several kilometres, e.g. to follow a marathon.

ANALOGUE RADIO CAMERA LIMITATIONS

Analogue radio cameras use FM (frequency modulation) to provide a signal with high linearity while using non-linear, but power-efficient, transmitters with an output power ranging 0.1 – 2 W. The radio link needs to be carefully set up to avoid interference to the picture. Sometimes this interference is from another transmission, but most troublesome is when it is self-inflicted through multipath propagation.

Multipath interference is caused by the signal reflecting off nearby structures and being picked up at the receive antenna with a delay with respect to the main signal. This causes a degraded picture and/or loss of synchronisation, which results in picture 'tearing'. In most situations, multipath is reduced by the use of a high gain receive antenna, typically a 120cm diameter dish that has to be panned by an operator to track the radio camera. Such a dish does not work well indoors due to multiple reflections off the walls finding their way into the dish.

The transmitted signal is circularly polarised to make use of the property that the sense of polarisation is usually reversed on reflection and so a receive antenna polarised for the signal will reject the reflection. This effect does not work well for ground reflections due the glancing angle.

Usually the radio camera antenna has an omnidirectional transmission pattern in the horizontal plane to allow freedom on movement. However, several schemes for having either a tracking or a switched-sector antenna on the camera have been tried to reduce the creation of multipath [1]. Various schemes for receiver diversity reception have been tried for analogue radio cameras, but they are not very successful due to the lack of a reliable method of detecting an impaired analogue video signal.

THE DIGITAL RADIO CAMERA TECHNICAL COMPROMISE

A digital radio camera is attractive because it is possible to use error protection techniques to improve immunity to interference. However, it brings various problems due to the limitations of spectrum, video coding, delay and modulation, and so a compromise must be reached.

Source picture

A digitised studio-quality 625-line picture needs at least 216 Mbits/s link capacity. It is clearly impractical to allocate sufficient spectrum, and so video compression is needed, but how much depends on the available spectrum channels. (Studio-quality HDTV needs over 1 Gbit/s.)

Spectrum channel width

The available spectrum channel width is usually 20 MHz in most spectrum bands, designed to accommodate analogue radio cameras. Therefore, 20 MHz sets a practical maximum bandwidth that can be used for a digital radio camera., with lower bandwidths being required as one way of accommodating increasing numbers of radio cameras.

Modulation scheme

It is clear that the high multipath immunity of COFDM (Coded Orthogonal Frequency Division Multiplexing) makes it more attractive than single-carrier modulation for digital radio cameras. The high immunity comes from a combination of multiple carriers (e.g. 2000), which gives long data symbols, plus the inclusion of a symbol extension, the guard interval, to allow time for echoes to die away. In addition COFDM generally has low out-of-band radiation which makes it easier to operate radio cameras in adjacent channels.

The multipath immunity of COFDM means that the receive antenna can now be a fixed wide-beam, or even omnidirectional antenna, placed to cover the operating area with line-of-sight reception without the need for somebody to steer it. In fact, if there are sufficient surfaces nearby, non-line-of-sight operation solely using the multipath reception is possible.

Developing a completely new modulation scheme for an emerging technology is expensive and time-consuming and so the first digital radio cameras tend to be based on the DVB-T standard developed for digital television [2]. DVB-T has a range of operating modes giving capacities ranging from about 5 Mbits/s to 31 Mbits/s all transmitted in a signal, an ensemble, occupying the same bandwidth, nominally 8 MHz in the UK. Generally, the three sets of half-rate coded modes are most suited to high multipath conditions due to their strong error protection. The most rugged mode (QPSK) has the lowest capacity:

QPSK / carrier:	5 Mbit/s capacity
16-QAM / carrier:	12 Mbit/s capacity
64-QAM / carrier:	18 Mbit/s capacity

Video coding and delay

The use of DVB-T for digital radio cameras suggests that video coding bit rates need to be in the range 4 – 17 Mbits/s (leaving some capacity for sound and ancillary data). Digital television uses bit rates around 3 - 5 Mbits/s and so it seems that there is ample capacity, but the video coding used is not best suited to digital radio cameras. Digital television uses MPEG2 (Motion Picture Experts Group 2) video coding with a long GOP (Group Of Pictures) structure [3]. Long GOP coding requires a large amount of processing on several picture frames to reduce the bit rate through prediction techniques, such as motion estimation. The resulting processing delay to the signal can be as high as 0.7 sec.

Digital radio camera pictures having a long delay are unacceptable in most situations. This is because at broadcasting events using both cabled and radio cameras, the difference in delay between the two types will be apparent to viewers on switching between cameras during the broadcast. This delay will be particularly noticeable at fast-moving sports events.

Another problem is the loss of synchronisation between the sound and picture when separate microphone systems are used. This loss of synchronisation can be very disconcerting to the viewer, especially when somebody is speaking to camera. The generally accepted video/audio delay difference limit is 40 ms. It is impractical to use compensating delays for all the microphones and cabled cameras at a large broadcast.

Short delay video coders either just code picture frames or fields individually or use prediction based on previous frames. In general, this limited prediction information means that the bit rate for a given quality has to be higher. In addition, broadcasters need pictures that start off at a higher quality than those broadcast because the picture is likely to encounter several video codecs as it is passes through the broadcasting process (e.g. satellite links, non-linear editors, tape recorders, etc).

Short-delay MPEG2 video coding is used for some digital radio cameras. The point where the picture quality becomes usable with only minor residual artefacts is about 10 Mbits/s. However, high quality pictures require in excess of 16 Mbits/s. These values are compatible with DVB-T modulation. Small low-power consumption MPEG2 coders have only recently become available. It is possible to achieve a delay of 40 ms with such coders, but using coding modes with an increased delay of 80 or 120 ms is still advisable for the most critical applications.

Another coding technique called DV (Digital Video) was developed for domestic digital camcorders, and so a compact low-power coder is available. DV has a video bit rate of 25 Mbit/s and the picture quality is arguably higher than MPEG2 at 16 Mbits/s. The quality is good enough that the broadcast equipment industry makes professional equipment based on DV or variants of it. The delay is about 100 ms, but the BBC has found that the delay can be accommodated by care in the ways the digital radio cameras are used.

There are other coding techniques, such as wavelets. Some of them may provide better coding efficiency, but implementations in compact circuits are needed for use in digital radio cameras.

THE BBC DIGITAL RADIO CAMERA.

Video coding and modulation

The compromise chosen in the BBC digital radio camera is to use the DVCPRO variant of DV combined with DVB-T modulation, Fig 1.

The coded video signal (about 30 Mbits/s including audio and framing) is split into two data streams, each formatted to resemble simplified MPEG transport stream. Two COFDM ensembles, each set to the rugged 64-QAM ½-rate mode, are used to transmit the signal. Although two DVB-T modulators are required in the transmitter, they are each mostly contained in two chips, making it practical to have this arrangement in a compact transmitter. Fig 2.

Fig 2. DVB-T modulator and I/Q upconverter card

RF upconversion

The output of each digital modulator is a multiplex of the I and Q components of the COFDM signal. These signals are upconverted directly to the 2.5 GHz channel using an I/Q modulator driven by a low-noise frequency synthesiser. This technique provides a frequency-agile transmitter without the need for bulky filters. This circuitry is contained on the same card as the COFDM modulator, see Fig 2. On upconversion, each of the ensembles is either given a positive or negative 4 MHz offset to create a dual-ensemble signal 16 MHz wide, which fits comfortably within a 20 MHz channel.

Power amplifier

The power amplifier produces an output of 100 mW. It has to be backed off by about 8 dB to avoid intermodulation products (IPs), that would affect the reception quality and cause adjacent-channel interference unless a bulky filter is used. The back-off reduces the amplifier's efficiency and so shortens battery life, but adding linearisation is not necessarily an advantage because the processing tends to consume as much power as is saved.

Antennas

Transmit. The transmit antenna is usually either a circularly polarised omnidirectional 'Fosda or Lindenblad', chosen mainly because they are available from analogue radio camera use. However, these antennas have a rather large white radome on the mast containing the antenna elements. This radome becomes obtrusive when the digital radio camera is getting close-up shots of the action but the programme director has chosen to give the viewer a wide shot. A small whip antenna, containing a vertical dipole, can be used in such circumstances.

Receive. Since COFDM modulation is multipath tolerant, the receive antenna does not have to be panned to track the radio camera. The choice of receive antenna is then governed by the area to be covered and the range required. Typically in a sports stadium uses a 90° fan-beam placed in the corner of the stands. As with the transmit antennas, circularly polarised antennas are often used because they are available.

If path-blocking is present, then it may be possible to find a site where the signal can reflect off a nearby structure. If this is not possible, then two or more antennas need to be used with a diversity receiver.

Experiments. Experiments with both linearly and circularly polarised antennas have showed no practical differences in performance between them. In theory, Circular polarisation would be useful to reject very short delay multipath, which defeats any modulation system through flat fading. Calculations show that, in the 2.5 GHz band, problems would only occur if the transmit antenna is closer than 8 cm to a surface. On the other hand, rejecting first reflections by using circularly polarised antennas removes a potentially useful contribution to the received signal. In practice path-blocking by the camera operator's body, when the camera is held low down, is more significant.

Receiver

The receiver contains a headend downconverter to amplify the signal at the point of reception and send it down a connecting cable at a lower frequency to reduce cable loss.

In the main receiver control unit, each ensemble in the signal is demodulated using a separate DVB-T demodulator based on a set-top box chip. The coded video stream is then reconstructed by combining the two halves received with reference to embedded packet numbers to identify their correct order.

The receiver sensitivity is about –82dBm for an ensemble pair which is about 5dB away from the theoretical limit for the mode in use.

Diversity reception is possible by daisy-chaining receivers together. The bit error indicators in the receivers provide flags for the diversity switch.

Ancillary signals

Television cameras are all slightly different, particularly in their colour balance, but it is difficult for a camera operator to make all the adjustments required, e.g. iris opening or closing, because of the need to concentrate on framing the shot and keeping the subject in focus. These extra adjustments are carried out remotely in the studio gallery or scanner vehicle, so signals need to be sent back to the camera. In the BBC digital radio camera, this is done using a VHF or UHF voice-band link and a modem to carry the adjustment signals as digital data.

PROGRAMME TRIALS

Digital radio cameras have been used on a wide variety of programme trials. Some examples are outlined here with particular emphasis on where usage is increasing because of their increased ruggedness [4].

Sports

Digital radio cameras are used in a wide variety of situations in sports to get close up to the action such as: two cameras on a football or rugby touch-line, close-ups of athletes being introduced at the start of a race, and interviews with breathless runners straight after crossing the finishing line. The BBC used seven digital radio cameras at this year's Commonwealth Games, limited only by the number of cameras available. Such large sports events could have in excess of forty cameras, and many of these could usefully be cable-free.

Golf is particularly challenging for digital radio cameras. Already, it is standard practice to rely on analogue radio cameras to follow golfers on the fairways. However, because the transmission distances are relatively large, up to several kilometres, and there are often trees causing path blockage, a two-path hop via a golf buggy as a frequency-transposing relay is often used, Fig 3.

Fig 3. A golf buggy used as a moveable relay

For analogue radio cameras, both the receive and retransmit antennas on the buggy have to be constantly aimed by the driver. A digital version would be able to use at least one omnidirectional antenna.

News

BBC News are using digital radio cameras to attend live breaking news events anywhere in the UK to provide immediate reports for BBC News 24 in addition to the normal news bulletins. The digital radio camera is able to move around a news event, usually in a public place, without any public safety problems through trialing cables. The ease of set up and lack of need to pan the receiving antenna is particularly useful to a news teams, which often only consists of two people. Although each news team may only have one or two cameras, there can be many news teams from various broadcasters at important events.

Pageants and events

The Queen's Golden Jubilee celebrations in the Mall were covered by six digital radio cameras in various ways. In particular, two cameras were used to move amongst the carnival participants and to hold interviews with then as they danced along the Mall. Another camera was used to obtain live pictures from a carnival float, with mixed success due to path blocking by the float's structure. Such large events could have around forty cameras, particularly if several broadcasters are present, again many of the cameras could be cable-free.

On location

Digital radio cameras have been used at various location events ranging from a production of Fidelio inside a circus tent, to interviews at a Proms concert at the Royal Albert Hall. At the Royal Albert Hall, three-way diversity reception was used to enable the interviewer to walk out of the main auditorium and along a crowded backstage corridor to hold an interview. Such events could have anything from five to twenty cameras present. The big advantage of cable-free cameras is that rigging and rehearsal times can be significantly cut, making large savings on production costs.

Digital radio cameras are very new to those working on such programmes, and so they are easily put off by any occasional picture break-up which can still occur, especially from interference.

Picture quality is also very important for such programmes, and the current DV-based system is only just acceptable. Some programmes are being made in high definition for sale abroad.

Studios

Studios are specifically designed for cabled cameras. however, there are some situations where digital radio cameras have been used, such as roving camera amongst a studio audience or the performers to avoid safety problems of having a cable. There is also a requirement for cameras to be able to follow people in and out of the studios.

Studio centres have a very high concentration of cameras. BBC Television Centre has eight main studios, each capable of having typically eight cameras. In addition there are several smaller studios.

As on location, picture quality is very important and even DV-based coding quality is not always adequate for standard definition television, let alone high definition.

Comments from users

Generally, programme makers are very pleased with the extra ruggedness of digital radio cameras and they are beginning to use the cameras in exciting ways. However, when signal loss or errors do occur, then the suddenness of the event, the digital 'brick-wall' effect, is disconcerting. There was a comfort amongst directors familiar with analogue radio cameras of seeing the impairment grow, giving time to switch to another camera before the screen went completely blank or frozen. It is important that spectrum for a digital radio camera is planned to allow a sufficient margin above the noise floor and against potential interfering signals to minimise the number of times the error protection is defeated. A picture break-up just once within the duration of a football match would actually represent a very high link availability in engineering terms, but would be seen as a broken radio camera by the director.

TECHNOLOGY TRENDS

Improving low delay video coders is key to reducing the spectrum requirements. However, at this time, most effort on video coding is aimed at low bit rate coding for Internet or mobile use, where either the quality or the delay is not suitable for use with digital radio cameras.

Improving the modulation is difficult because even if a better scheme is devised, unless it finds a mass market application, equipment built using it is unlikely to be competitive against that using DVB-T chips. Even if a mass market application did come about, it is likely to use a lower bit rate than that required for studio quality radio cameras.

There is already a move towards bigger television displays in the home, so viewers are likely to become more aware of picture quality. If high definition broadcasting starts in the UK, then the quality of digital radio cameras will need to improve.

Cabled cameras often receive a return video feed from the vision mixer that is available to be switched into the camera viewfinder by operator. The return video has several uses, in particular, it helps the operator frame up a shot in relation to a caption. Spectrum for a wireless return video feed will be needed. Due to the small viewfinder, the return video can have a lower quality and be in black-and-white, but the delay must still be short to avoid disorientating the camera operator. Hence the bit rate could probable be lower than that for the forward channel, but it still expected to be in the range 1 - 4 Mbits/s.

SPECTRUM REQUIREMENTS

Channel requirements

Work on the standardisation of digital video links in ETSI TG17 WG4 has taken the current 20 MHz channels and proposed that they be made divisible into 10 and 5 MHz channels for various classes of digital video equipment (professional, business and domestic). There is an implied assumption that the extra channels needed for more digital radio cameras will be found by this subdividing process.

There is a trend amongst digital radio camera manufacturers to use a single DVB-T ensemble and MPEG2 video coding. This suggests that the 10 MHz channel will become the norm for most programme-making applications. Increasing spectrum efficiency by having 5 MHz channels will require improved video coding and modulation techniques.

The 20 MHz allocation will still be required for the foreseeable future for the BBC's dual-ensemble system. Even if low-delay video coding does improve to provide 'broadcast' quality in a single COFDM ensemble, it is likely that programme makers will start to demand higher quality digital radio cameras as they make more high definition programmes. The BBC's system already has the capacity to carry up to 36 Mbits/s.

Transmitter standards

Digital equipment is affected by interference in a different way from analogue equipment, and so transmitters need to have their output characteristics defined differently.

The BBC has recently proposed within TG17 WG4 that a spectrum mask be adopted for digital wireless video which sets limits for the total out-of-channel power in adjacent and next-adjacent channels, Fig 4. This contrasts with a typical mask for analogue FM, which prescribes a particular shape for the transmitted spectrum. This proposal is intended to allow flexibility in the way the allocation is used, whilst protecting adjacent users from undue interference. For instance, the power in region 1 of Fig 4 should not exceed the allowable limit for the transmission type. The adjacent channel power in region 2 is set a prescribed limit, without using a 'mask' as such, and so on for regions 3 and 4. In this way the modulation type and the precise nature of the out-of-band emissions are left undefined for flexibility, but the adjacent channel user knows what interference level to expect.

Measurements on spectrum

The 2.5 GHz band preferred for digital radio camera operation will be lost to the extension of 3G mobile at the end of 2005. It has been suggested that digital radio cameras could share the 2.4 GHz ISM band. Putting aside the major problem that there are only four 20 MHz channels in the ISM band compared to the ten channels above it, there is the question of the effect of interference from licence-free equipment.

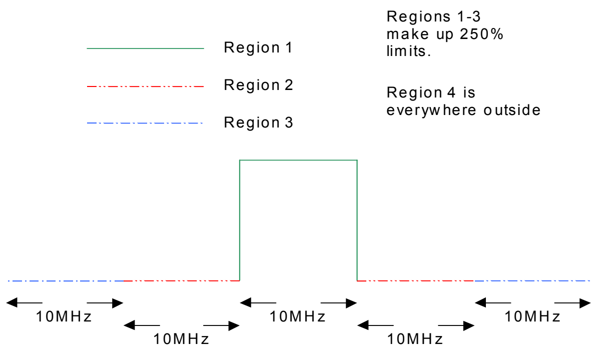

Fig 4. Spectrum mask proposal for digital video links

Initial tests by the RA and JFMG Ltd from the top of the Barbican's Cromwell Towers, City of London, showed that there is a big difference in the amount of interference in the 2.4 and 2.5 GHz bands, Fig 5. Note that only licensed transmissions can be seen in the 2.5 GHz band.

In order to determine what this means for a digital radio camera operating in the streets of London, e.g. at a news event or a pageant, a further series of tests were carried out from a vehicle driving around various London locations. These tests used DVB-T equipment to directly determine the effect of the interference on a digital radio camera signal through the equipment's inbuilt error monitoring.

An initial assessment of the results confirms that the ISM band is substantially inferior to the 2.5 - 2.7 GHz band in terms of interference. Even operating with substantially more transmitter power, equipment in the ISM band produced poorer results in terms of bit error rate. A more detailed analysis of these results will be given in the presentation.

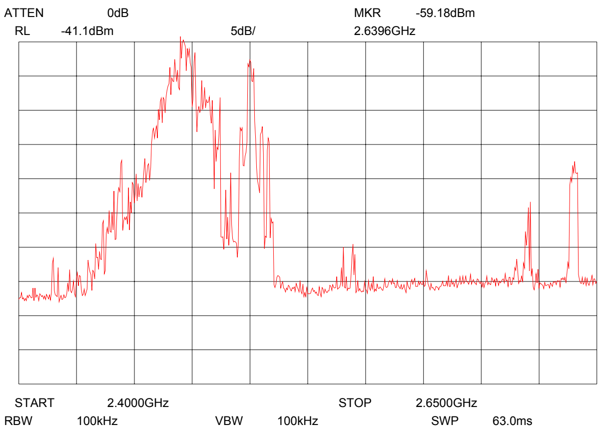

Fig 5. Comparison of the 2.4 and 2.5 GHz bands in London

Spectrum bands

Currently, digital radio cameras use the 2.5 GHz band, but this band is being lost to the extension of 3G mobile, and so replacement spectrum will be needed to replace the 200 MHz of spectrum that has to be given up. There are pockets of alternative spectrum allocated to broadcasters between 3.5 and 12 GHz, but these are already used for other video links and so will be put under greater pressure if digital radio cameras are moved there.

The previous discussion has suggested that there will be an increase in demand for digital radio cameras now that their reliability has been proven. Where can enough spectrum be found for forty digital radio cameras at a large sporting event? This represents between 400 to 800 MHz depending on which system is used. It seems that the higher microwave bands will have to be used, but the DVB-T standard generally does not work well above about 3.5 GHz.

The version of DVB-T used in digital radio cameras has just under 2000 carriers, spaced at 4 kHz. This limits the differential Doppler multipath immunity to about 40km/h at 3.5GHz for rugged 64-QAM mode.

It may be possible to use the higher microwave bands, e.g. 12 and 24 GHz, indoors, where Doppler is lower. which would be useful for studio and some location applications. Also, the studio walls would provide shielding helping to allow channels to be reused. Outdoor operations would either need a new modulation scheme or alternative spectrum below 3.5 GHz. The lower frequency bands are preferred because of the benefits of higher diffraction round obstructions and lower rain attenuation.

Currently, there are only five 20 MHz channels in the 3.5 GHz band. Recently, the 2.0 – 2.2 GHz band has been proposed and would be very useful to ease the problem of losing the 2.5 GHz band.

Additional spectrum will be required for a return channel to the camera for camera control and return video. The return video will put the major demand on spectrum because the bit rate will need to be high enough to minimise the coding delay.

At this time there doesn't seem to be enough spectrum available to meet the expected growth in digital radio camera usage by broadcasters. This doesn't even take into account all the other potential uses for digital radio cameras, such as security, surveillance, and other uses in industry.

CONCLUSIONS

Digital radio cameras are beginning to become widely used in broadcasting. The requirement for high quality pictures using low delay coding techniques demands sufficient operating channel bandwidth to carry the required bit rate. Increased use of digital radio cameras comes at a time when the currently used spectrum is being re-allocated to other purposes. Therefore, more replacement spectrum will be needed than is being relinquished. Suitable spectrum for indoor uses might be found in the higher microwave bands, but outdoor operations requires spectrum below about 5 GHz to reduce the effects of differential Doppler multipath.

ACKNOWLEDGEMENTS

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