IEEE 802.11

Wireless MAC and PHY specification
Archive

First draft

The IEEE 802.11 Working Group maintains this loose leaf document to archive the results of discussions, studies and measurements.

The goal of this document is to provide an orderly base of facts to prevent unnessecary repetitions of debates. It also provides a method to bring new members efficiently on level with the groups background.

The outline of this document is as follows:

Project Authorization

Procedures

Questions

This section contains the questions put in front of the Working Group which, when answered would yield the standard.

All submissions to the Working Group are to be directed to one or more of these questions.

The questions are organized in the following sections:

- Architecture
- Network Management/System Management
- Distribution System
- MAC
- PHY
- Medium
- Regulation
- Miscellaneous

Positions and answers

In this section, positions considered or taken against the questions are recorded in the so-called IBIS format. IBIS format allows for the recording of arguments in favour and against possible positions. Even rejected positions are kept on file; when new ideas come up, it is easily verified against the arguments that lead tot he rejection of the position.

Definitions

Reference documents

Supporting Information

I. Project Authorization

The following is the text of the PAR as drafted at the September 1990 meeting of the Working Group. Both the Executive Committee and the Working Group have the option to change its contents before it is being sent to the TCCC.

6. Scope of proposed standard

To develop a Medium Access Control (MAC) and Physical Layer (PHY) specification for wireless connectivity for fixed, portable and moving stations within a local area.

The goal is that the MAC shall support PHYs using electromagnetic waves through the air (i.e. radio waves as well as infra-red or visible light)

The standard shall support stationary stations, movable stations, and mobile stations moving at pedestrian and vehicular speeds. This is to be implemented with one PHY if feasible.

Because the range of wireless transmission / reception may be smaller than the physical coverage area desired, a distribution system designed to provide range extensibility will be addressed as part of this standard.

PHY layer suitable for use with unlicensed RF equipment will be defined with this standard. If evidence of need and sufficient interest exists other PHY layers will be considered at a later time.

Currently the only available spectrum is in the ISM bands in the USA provisionally 915 MHz band in Canada and Australia. Test programs are underway in the UK and elsewhere, evaluating license free operation.

Therefore the initial work of this committee will be for the ISM bands.

However, these bands are already heavily used, and it is felt that service degradation from other users will happen, increasing with time. Therefore, in order to further development of the standard, the 802.11 committee should participate in the development of changed or new regulations for short distance radio services in which all authorized users of any new frequency allocation shall be permitted to radiate only a defined maximum power density.

To further enhance the standard the 802.11 committee will undertake to document the benefits of, and make recommendations for international standardization where possible.

Supported environments include:

* **in buildings such as offices, financial institutions, shops, malls, small and large industry, hospitals,**
* **outdoor areas such as parking lots, campuses, building complexes and outdoor plants and storages.**

Note: The definition of performance classes within a PHY may be necessary to support environments with benign or hostile characteristics.

The standard will include support of the following:

- **Basic Service Area (BSA)** — **in which each station can communicate with any other station in the BSA.**
- **Extended Service Area (ESA)** — **in which each station can communicate with any other station via the defined and managed Distribution System.**

Stations which interoperate in both BSA and ESA shall be defined if feasible.

The Wireless MAC shall support both connectionless service as defined in the MAC Service definition at rates between 1 and 20 Mbit/s as well as a service supporting packetized voice.

The specification shall meet the following standards and documents:

- **the IEEE P802 Functional Requirements except that:**

  * **The proposed standard will meet all of the 802 Functional requirements, except that the probability that a MAC Service Data Unit (MSDU) reported at the MAC service interface contains an undetected error, due to operation of the conveying MAC and Physical Layer entities, shall be less than 5*10E-14 per octet of MSDU length and the MSDU loss rate will be less than 4*10E-5 for MSDU length of 512 octets, in a minimally conformant network.**

    A minimally conformant IEEE 802.11 network will meet these requirements over a minimally conformant radio service area. IEEE 802.11 will define standard approaches to allow minimally conformant systems to be enhanced to achieve full 802 functional requirements over the radio service area.

    Definitions

    Minimally conformant radio service location - a physical location at which radio service is available at least 99.9% of the time on an daily basis.

    Minimally conformant radio service area - physical area in which at least 99.9% of the total geography consists of minimal conformant service locations.

  * **transmissions of one node do not necessarily have to be received by all other nodes simultaneously.**

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IEEE 802.2/ISO 1003x,	**the MAC service Definition**
IEEE 802.1 A	**Overview and Architecture,**
IEEE 802.1 B	**for LAN/MAN Management,**
IEEE 802.1 D	**for T and SRT bridges,**
IEEE 802.1	**F for Guidelines for the Development of Layer Management Standards,**
IEEE 802.10	**Secure Data Exchange.**

The MAC design shall anticipate restriction on low-frequency pulsing below 100 Hz of Electromagnetic fields due to biological hazards.

7 Purpose of proposed standard.

To provide wireless connectivity to automatic machinery, equipment or, stations that require rapid deployment, which are portable, or hand-held or which are mounted on moving vehicles within a local area

To provide a standard for use by regulatory bodies to control the shared use of one or more radio frequency bands.

Note: To make this purpose feasible, this PAR also authorizes IEEE 802 to petition or provide comments to requlatory bodies worldwide (e.G. the FCC in the USA, the Department of Communications in Canada, the RF agency of the Department of Trade and Industry in the UK and the Radio Frequency Commission of the CEPT of Europe)

10 Target completion

Architecture definition available	March 1991
First draft standard ready for ballot in 802.11	Nov 1991
First draft conf standard ready for ballot in 802.11	March 1992
TCCC ballot of MAC & PHY standard	July 1992
TCCC ballot for conf standard	Nov 1992
Submission to ISO of MAC & PHY standard	Dec 31, 1992

11 Proposed Coordination

CCIR Interim Working Party trusted with q AM/8	draft circulation
CEPT/RFC/FM	draft circulation
ETSI	corresp/common membership
ECMA	corresp/participation
Worldwide Regulatory bodies	correspondence
ISA SC-50	Common membership
IEEE Vehicular Technology Society	Liaison
SCC10?	Liaison
ANSI X3S3	Liaison
IEC/TC83? fiber optics only	
ISO/IEC JTC1/SC6/WG1	
TCMM/MSC	circulation of drafts
ANSI ASC T1 advisory group in T1E1	correspondence
TIA telecom Industry Association	TBD
Include SAE, the society of Automotive Engineers	TBD
ACM? Association of Computing Machinery	TBD
ETSI RES ?	draft circulation

II. Procedures

The IEEE P802 Operating Procedures are adopted for the operation of Working Group P802.11. A copy is given below.

Normally a vote is carried if there is 75% approval among those voting Approve and Do Not Approve. It was agreed that if only a simple majority is achieved then the issue should be held as an open issue. It was also agreed that if at least 75% approval is achieved, but in the opinion of the officers (chair, vice chair, secretary, editors) there is significant disagreement, (particularly one that may result in ISO no votes,) the issue will not be closed.
It was agreed that members and observers who have attended at least one working group or task group meeting in the last four meetings, will receive the full set of documentation.
The minutes will contain attendance lists, corporate affiliations, and telephone numbers.
A Working Group document ordering system is in study.

Distributed documents will be given attention first, late written documents (bring 50 copies if possible) will be given attention next and Ad Hoc contributions will be given attention last

Begin quote:

4. PROJECT 802 WORKING GROUPS

4.1 Function

The function of the Working Group is to produce a draft standard, recommended practice or guideline. These must be within the scope of Project 802, the charter of the Working Group and an approved PAR or a PAR under consideration by the IEEE Standards Board as established by the Executive Committee. After the issuance of the Working Group's standard, recommended practice or guideline, the Working Group's function is to review and revise it as necessary.

4.2 Chair

The Working Group is led by a Working Group Chair, initially appointed by the Executive Committee and then confirmed or elected by the members of the Working Group. The Working Group Chair is reaffirmed by the member of the Working Group at the first Plenary Meeting of each even numbered year.

4.3 Membership

4.3.1 Establishment

All persons participating in the initial meeting of the Working Group become members of the Working Group. Thereafter, membership in a Working Group is established by participating in two out of the last four Plenary meetings of the Working Group and (optionally), a letter of intent to the Chair of the Working Group (Membership starts at the third meeting). One duly constituted interim working group ~~or task group~~ meeting may be substituted for one of the two Plenary meetings.

No participation credit will be granted to any individual who has outstanding financial obligations to Project 802; retroactive credit for participation in meetings shall not be granted if payment is not made prior to the start of the next meeting. (Note: Assumes Project 802 Treasurer personally contacts individual, verbally or in writing, but with some assurance communication was, in fact, received and in sufficient time to respond.)

4.3.2 Retention

Membership is retained by participating in at least two of the last four Plenary meetings. One duly constituted interim working group ~~or task group meeting~~ may be substituted for one of the two Plenary meetings. Participation is defined as at least 75% presence at a meeting. Membership may be declared at the discretion of the Working Group Chair (for contributors by correspondence or other significant contributions to the Working Group). Membership belongs to the individual, not an organization, and may not be transferred.

4.3.3 Loss

Membership may be lost if two of the last three letter ballots are not returned or returned with an abstention other than "lack of technical expertise~~"~~." This rule may be excused by the Chair. Membership may be re-established as if the person were a new candidate member.

4.3.4 Rights

The rights of the Working Group members include the following:

a) Notice of the next meeting.
b) Copy of minutes.
c) Voting at meetings if and only if present.
d) Voting by mail on drafts to be submitted to TCCC.
e) Examine all Working Draft documents.
f) Lodge complaints about Working Group operation with the Executive Committee.
g) Petition the Executive Committee in writing. (A petition signed by two-thirds of the combined voting members of all Working Groups ~~and TAGs~~ forces the Executive Committee to implement the resolution.)

4.3.5 Meetings and Participation

Working Group meetings are open to anyone. Only members have the right to participate in the discussions. The privilege of non-members to participate in discussions may be granted by the Chair.

Interim Working Group or Task Group meetings, as a goal, are to have: 1) Reasonable notification (>4 weeks), 2) Few shifts in location (<< 1 per year), and 3) Notify all Working Group voters, observers and liaison people (Notice at Plenary, written announcement if not at Plenary).

4.4 Operation of the Working Group

The operation of the Working Group has to be balanced between democratic procedures that reflect the desires of the Working Group members and the Working Group Chair's responsibility to produce a standard in a reasonable amount of time. The operating rules below are designed to achieve this balance~~:~~.

4.4.1 Chair's Function

The Chair of the Working Group decides procedural issues. The Working Group members and the Chair decide technical issues by vote. The Chair decides what is procedural and what is technical.

4.4.2 Voting

There are two types of votes in the Working Group. These are votes at meetings and votes by letter ballot.

4.4.2.1 Voting at Meeting

A vote is carried by a 75% approval of those members voting "APPROVE" and "DO NOT APPROVE". No quorum is required at meetings held in conjunction with the Plenary. The Chair may vote at a meeting. A quorum is at least one-half of the Working Group ~~or TAG~~ voting members.

4.4.2.2 Voting by Letter Ballots

The decision to submit a draft standard or a revised standard to the TCCC must be ratified by a letter ballot. Other matters may also be decided by a letter ballot at the discretion of the Chair. The Chair may vote in letter ballots.

The letter ballot response time must be at least forty days from the time of "sending" postmark to the postmark of the returned ballot.

The ballot contains three choices:

- Approve. (May attach non-binding comments.)
- Do Not Approve. (Must have specific comments on what must be done to the draft to change the vote to "Approve".)
- Abstain. (Must include reasons for abstention).

To forward a draft standard or a revised standard to the TCCC, a 75 percent approval is necessary with at least 50 percent of the members voting. The 75 percent figure is computed only from the "Approve" and "Do Not Approve" votes.

The Chair determines if and how negative votes in an otherwise affirmative ballot are to be resolved.

Submission of a draft standard or a revised standard to the Executive Committee must be accompanied by any outstanding negative votes and a statement of why these unresolved negative votes could not be resolved.

4.4.3 Chair's Responsibilities

The main responsibility of the Working Group Chair is to produce a draft standard or to revise an existing standard. The responsibilities include:

a) Call meetings and issue notice at least four weeks prior to the meeting.
b) Issue minutes and important requested documents to members of the Working Group, the Executive Committee, and liaison groups. The minutes are to include:

    - List of participants
    - Next meeting schedule
    - Agenda as revised at the start of the meeting
    - Voting record
        . Resolution
        . Mover and second
        . Numeric results

Sufficient detail shall be presented in the minutes to allow a person knowledgeable of the activity, but not present at the discussion, to understand what was agreed to and why.

Minutes shall be distributed within 45 days of the meeting to the attendees of the meeting, all voting members and all liaison people.

c) Maintain liaison with other organizations at the direction of the Executive Committee or at the discretion of the Chair with approval of the Executive Committee.

If in the course of standards development any Project 802 Working Group ~~or Task Group~~ utilizes a standard developed or under development by another organization within 802, by another IEEE group or by an external organization, the 802 group shall reference that standard and not duplicate it.

If a standard cannot be utilized as is and modifications or extensions to the standard are necessary, the group should:

1) Define the requirements for such changes.

2) Make these requirements known to the other organization and;

3) Solicit that organization for the necessary changes.

Only if the required changes cannot be obtained from the other organization, can the group, with the concurrence of the Executive Committee, develop these changes itself. Even in the latter case, the Project 802 group should seek the concurrence of the other organization by joint meetings, joint voting rights or other mechanisms on the changes being made.

d) Provide a full accounting to the Project 802 Treasurer of all fees collected and retained, under authority of section 4.4.4.h, to meet Working Group expenses, and the disposition of these funds.

4.4.4 Chair's Authority

To carry out these responsibilities, the Chair~~man~~ has the authority to:

a) Call meetings and issue minutes.
b) Decide which issues are technical and which are procedural.
c) Establish Working Group rules beyond the Working Group rules set down by the Executive Committee. These rules must be written and all Working Group members must be aware of them.
d) Assign/unassign subtasks and task leaders or executors, e.g. secretary, subgroup chair, etc.
e) Speak for the Working Group to the Executive Committee.
f) Determine if the Working Group is dominated by an organization and treat that organizations' vote as one (with the approval of the Executive Committee).
g) Make final determination if and how negative letter ballots are to be resolved ~~and if~~when a draft standard is to be sent to the Executive Committee and TCCC.
h) Collect fees to meet Working Group expenses.

4.4.5 Precedence of Operating Rules

If Working Group operation conflicts with the Operating Rules of IEEE Project 802, then the Operating Rules of IEEE Project 802 shall take precedence.

4.4.6 Deactivation of Working Group

Deactivation of a Working Group shall require approval of the Project 802 Executive Committee.

End quote

III. Questions

Currently the only questions under consideration are those concerning architecture. After the architecture has been established, the questions for the further development will be prepared.

?I: What should be specified in a standard satisfying PAR 802.11a?

?I: What is the WLAN Architecture?
?I: What services are required from the WLAN?
?I: What scenarios in topology are of interest?
?I: Which functions are required to support the services and topologies
?I: What is the best placement of the function.

IV. Positions and arguments

What is IBIS:

IBIS means Issue Based Information Systems, it presents a method of documenting discussions.

IBIS consists of 3 key elements (nodes): Issues, Positions and Arguments.

Issues	:	An Issue articulates a key question.
Position	:	A position makes a single point that directly addresses its parent issue.
Argument	:	An argument supports or objects to a Position.

IBIS notation (text indentation method):

The textual format of IBIS uses indentation to represent the hierarchical relationship among nodes. The labels used for different types of nodes are:

Issues, Positions and Argument nodes are labeled:

I:	issues
P:	positions
A+:	supporting arguments
A-:	objecting arguments

Each node label is preceded by a status flag.

?	open node:	for positions: no decision made for questions: question is not agreed by the committee
*	agreed node	for question: Committee agreed to work on the question for position: accepted by the comittee for argument:.committee accepted argument as valid
-	rejected node.	for position: committee agreed to reject the position
>	Issue resolved,	The committee has closed the issue

Issues have been numbered for easy reference.
Within an issue the positions are numbered.

The format is thus:

1 *I: What is the layout for text indentation IBIS?

*P: The base Issue at the left margin.

*P: The Position(s) 1 TAB indented under the Issue.

*P: The Argument(s) 1 TAB indented under the Position.

1.1 *I: Can a node have more than one line of text

*P: Yes. This position is an example of a position being printed on more than one line.

1.2 *I: Can a new issue be raised at all types of nodes.

*P: Yes it can.
*A+: Questions can raise everywhere.
1.2.0.0.1 ?I: Is this a valid argument?

V. Definitions

To be supplied

VI. Reference documents

The following papers are of interest to the taskgroup members:

Environmental Monitoring for Human Safety Part 1: Compliance with ANSI Standards. By John Coppola and David Krautheimer, Narda Microwave Corporation. - RF Design--.
RF Radiation Hazards: An update on Standards and Regulations. By Mark Gomez, Assistant Editor, and Gary A. Breed, Editor. - RF Design, October 1987
RF Radiation Hazards: Power Density Predeiction for Communications Systems. By Gary A. Breed, Editor. - RF Design, December 1987
Microprocessor Interference to VHF Radios. By Daryl Gerke, PE Kimmel Gerke & Associates, LTD. - RF Design, March 1988
Distributed Antennas for Indoor Radio Communications. By Adel A.M. Saleh, A.J. Rustako, Jr and R.S. Roman. - IEEE Transactions on Communications, Vol. Com-35, No12, December 1987
UHF Fading in Factories. By Theodore S. Rappaport and Clare D. McGillem. - IEEE Journal on selected Areas in Communications. Vol. 7. No 1. January 1989
Indoor Radio Communications for Factories of the Future. By Theodore S. Rappaport. - IEEE Commmunications Magazine. May 1989.
A differential offset QPSK modulation/demodulation technique for point-to-multipoint radio systems. By Tho Le-Ngoe. GLOBECOM 87.
Highly Efficient Digital Mobile Communications with a Linear Modulation Method. (p/4 QPSK) By Yoshihito Akaiwa and Yoshinori Nagata. - IEEE Journal on Selected Areas in Communications. Vol. SAC-5, No. 5, June 1987, pp.890-895.
Multi-Frequency Radiowave Propagation Measurements in the Portable Radio Environment. By D.M.J. Devasirvatham, C. Banerjee, M.J. Krain and D.A. Rappaport. - IEEE Communications Society, "IEEE International Conference on Communications", April 16-19, 1990, pp 1334-1340.
Time Delay Spread Spectrum Measurements at 850 MHz and 1.7 GHz inside a Metropolitan Office Building. By D.M.J. Devasirvatham, R.R. Murray, C. Banerjee. - Electronics Letters 2nd february 1989, Vol 25 No. 3.

IEEE p802.4L/89-19 Statistic analysis of Oshawa analysis. By L. van der Jagt, KII
IEEE p802.4L/90-08a IEEE 802.4L Submission on Microwave Oven Interference Measurement. By Jonathon Cheah, Hughes Network Systems.

VII. Supporting information

VII A Propagation

Office/retail environment: 6 dB/octave under 10 meters

Local Spatial Correlation (LSC) is defined as follows:

Let,

$A(\tau,x)$ = The signal attenuation of the impulse response amplitude in dB at excess time τ and position x.

$M_A(\tau,x)$= The local spatial average of the signal attenuation at excess time τ in the vicinity of location x.

Rappaport reports that $A(\tau,x)$ was found to be approximately normally distributed with a mean of $M_A(\tau,x)$. The local spatial correlation (LSC) is,

$$LSC(\tau,\Delta x) = \frac{E[(A(\tau,x)-M_A(\tau,x))(A(\tau,x+\Delta x)-M_A(\tau,x))]}{E[(A(\tau,x)-M_A(\tau,x))^2]}$$

Much the same as for the coherence time and the spaced-time correlation function, coherence distance could be defined as the value of Δx at which LSC becomes = 0. The local spatial correlation is about 0.2 at $\lambda/4$ and effectively 0 at $\lambda/2$ at nearly all values of excess delay. Thus coherence distance is approximately $\lambda/2$ in the Rappaport measurements.

environment	20 meter attenuation relative to 1 meter (dB)	slope (dB/octave)	standard deviation (dB)	RMS delay spread (within 20 dB from max peak) (ns)	notes	Local Spatial Correlation	Coherence Time
open retail	29-35	10-13.8	2.1-5.3	10-150	1		
obstructed retail	40	19.4	4.5	not measured	2		
factory	25-32	5.7-7.3	4.8-10.2	30 min 160 (95%) 280 max	3		
office	39 1 location	11.7 1 location	2.2 1 location	10-50	4		

Note 1: The open retail environment consists of a typical department store or supermarket with no more than 1 floor-to-ceiling wall in any path. Some otherwise shaded paths are included. These include paths shaded by elevator shafts and by concrete columns as well as merchandise and displays in the line-of-sight paths. The size varies from 21 meter maximum linear dimension to 110 meters maximum linear dimension.

The lowest delay spreads were measured in a small supermarket. These delay spreads were measured indirectly using the coherence bandwidth method. The variation of 4 measurements was 8 to 20 ns (coherence bandwidth of 8 to 20 MHz). The larger delay spreads were measured using the direct impulse response power delay profile. Values in large department stores are 50 to 150 ns.

The attenuation statistics (first 3 columns) were taken with CW measurements and were recorded separately for each location. The first 2 column parameters were computed by finding the set of values which minimized the standard deviation (third column). The standard deviation is that of the deviation from a regression line of 0 dB at 1 meter and 6 dB/octave (straight line against log distance) from 1 meter to the point where the low slope line intersects the higher slope line. An iterative procedure was used which varied the slope and 20 meter attenuation of the higher slope segment for minimum RMS deviation.

Note 2: The obstructed retail location was a department store with multiple floor-to-ceiling walls. Wall attenuation was measured at approximately 6 dB/wall. The maximum linear dimension of this store was 100 meters. There were approximately 10 walls in the longest paths.

Note 3: The factory information is from the report *Characterization of UHF Factory Multipath Channels* by Theodore S. Rapport and Claire D. McGillem, School of Engineering, Purdue University, West Lafayette, Indiana 47907, TR-ERC-88-12.

5 Light to heavy manufacturing locations were measured.

The attenuation statistics (first 3 columns) differ from the retail and office statistics in the manner in which the large scale loss curve fit was computed. The 10λ distance is the reference. The curve (regression line) was forced to 0 dB at the reference point and there is only one curve segment. The slope (second column) of the regression line is the value which minimizes the standard deviation (third column). The principal difference is that the regression line for the retail and office statistics was not forced to a particular point, but was allowed to vary in the vertical dimension to further minimize the standard deviation. Thus, the standard deviation of the factory measurements can be expected to be higher than that which would be determined by the retail and office environment method and the slope can be expected to be different. Rappaport reported that the techniques differ by no more than 0.2 dB in standard deviation and 1.5 dB/octave in slope.

Rappaport also computed attenuation values from the 50 wideband measurements made over the 5 sites. The attenuation values were computed from the impulse response power-delay profiles. The result for all sites was:

20 meter attenuation relative to 1 meter (dB)	slope (dB/octave)	standard deviation (dB)
26	6.5	4.9

The delay spreads were from the 50 wideband measurements. They were further broken down into those for obstructed paths (OBS) and line-of-sight (LOS) paths:

	Min.	50 Pctl.	95 Pctl.	Max.
OBS	30 ns	110 ns	140 ns	155 ns
LOS	30 ns	90 ns	150 ns	280 ns

The second largest RMS delay spread was 155 ns.

Note 4: The office environment information is from measurements of an engineering office location in The Netherlands and from the article *A Statistical Model for Indoor Multipath Propagation* by Adel A. M. Saleh and Renaldo A. Valenzuela, IEEE Journal on Selected Areas in Communications, Vol. SAC-5, No. 2, Feb., 1987.

The attenuation measurements are from the office location. *(Note: I do not have a copy of the article. Further attenuation information is probably included. Perhaps this can be added later)*

The maximum office delay spread (50 ns) is the maximum reported by Saleh and Valenzuela. In addition, the coherence bandwidth was measured for two paths in the office location. Coherence bandwidths were 8 and 16 MHz, corresponding approximately to RMS delay spreads of 20 and 10 ns.

Subject	Base	Doc no

Directions (cont..d)

Coherence time is defined as follows:
Given a time-variant (wide-sense stationary) channel impulse response of

$$c(\tau;t) = \alpha(\tau;t)\ e^{-j2\pi f_c \tau},$$

where τ is the delay and $\alpha(\tau;t)$ is the attenuation of the signal components at delay τ at time instant t.

Let $C(f;t) = \int_{-\infty}^{+\infty} c(\tau;t)\ e^{-j2\pi f\tau}\, d\tau$ be the Fourier transform of this impulse response.

$$\phi_c(f_1, f_2; \Delta t) = 1/2\ E\ [(C^*(f_1;t)\ C(f_2; t+\Delta t)] = \phi_c(\Delta f; \Delta t),$$

where E is expectation, is called the spaced-frequency spaced-time correlation function.

Holding Δf to 0 gives the spaced-time correlation function. The period of time over which the magnitude of this function is essentially non-zero is the coherence time of the channel.

Noise:

Jan 89

at 902-928 MHz	10 dB above thermal	
at 2400-2483.5 MHz	thermal	Jan 89

Contributions on noise are requested in the following format:

Device	Band	distance from source	Power *) level	Number of hits per second Threshold			
				-10 dB	-20 dB	-30 dB	-40 dB
		m	dBm				

Table 2. Characteristics of impulsive noise generators

Device	Freq	Power		Bandwidth	Duty cycle
		EIRP	Receive level		
	MHz	W	dBm	kHz	
(1)	(2)	(3)	(4)	(5)	(6)
Pager	931.6125	340		15	5 sec/call 1 call/5 min
Radio Channel	904			30	continuous
Pager	930.0		- 50 indoor	15	5 se/call 1 call/min
Field disturbance sensors	902-928	0.075		<1	continuous
Part 15 devices	902-928 2400-2483.5 5725-5875	.00075			
Digital oscillators					
Digital devices					

Table 3. Characteristics of Constant Wave Interferers

NOTES:
* reference antenna : dipole for the appropriate band
distance from source > 1 m
vary measurements over a sphere with at least 10 measurements
* for impulsive noise measurements: make the measurements in the time domain
* for CW measurements: include a graph of frequency versus time behavior for sweeping devices, e.g. microwave ovens.

It appears that the magnetron has a negative resistance on turn-on and turn-off, and this causes relaxation oscillations at the beginning and end of each power cycle, which cause an apparent broadband emission. In reality, during the beginning and end of each power cycle, the magnetron produces a series of very short bursts of carrier (<< 300 ns each) with decaying power and a frequency which changes slightly during the burst, and with more substantial changes in frequency from one burst to the next.
In the middle of each power cycle the magnetron just stays on, with occasional instantaneous frequency changes due to shifts in mode-locking caused by the changing magnetron plate voltage and the motion of the stirrer in the oven cavity. (See addendum L1, and IEEE 802.4L-89/19 for time domain pictures of this phenomenon.) These instantaneous changes may be accompanied by additional bursts. (See IEEE 802.4L/90-8a figure 4-46.)

8. Noise immunity vs spreading.

Constant Power, Varying Chip Rate, Constant Symbol Rate

Quantity	Formula or Nomenclature	$N_c = 1$ Base Case	$N_c = 11$ vs $N_c=1$	$N_c = 127$ vs $N_c=1$
# chips/symbol	N_c	1	11	127
Symbol period (s)	T_s	10^{-6}	1	1
Symbol rate (symbol/s)	$1/T_s$	10^6	1	1
Chip period (s)	$T_c = T_s/N_c$	10^{-6}	1/11	1/127
Chip rate (chip/s)	N_c/T_s	10^6	11	127
Symbol energy (J)	E_s	10^{-6}	1	1
Chip energy (J)	$E_c = E_s/N_c$	10^{-6}	1/11	1/127
Signal out of correlator (V)	$N_c \sqrt{E_s/T_s}$	$\sqrt{E_s/T_s}$	11	127
RMS noise into correlator (V)	$\sqrt{N_o N_c/T_s}$	$\sqrt{N_o/T_s}$	$\sqrt{11}$	$\sqrt{127}$
RMS noise out of correlator (V)	$\sqrt{N_c}\sqrt{N_o N_c/T_s}$	$\sqrt{N_o/T_s}$	11	127
Avg. signal to RMS Gaussian noise out of correlator		$\sqrt{E_s/N_o}$	1	1
E_s/N_o improvement from spreading (dB)		0	0	0

Incoherent Line Interferers Uniformly Distributed in Band (i.e., number increases with bandwidth)

$$L(t) = \sqrt{2} \sum^{\kappa N_c} L_i \cos(\omega_i t + \phi_i) \qquad \text{where } \omega_i/2\pi < B_c$$

Interference power into correlator (W)	$\sum^{\kappa N_c} L_i^2$	$\sum^{\kappa} L_i^2$	11	127
RMS interference into correlator (V)	$\sqrt{\sum^{\kappa N_c} L_i^2}$	$\sqrt{\sum^{\kappa} L_i^2}$	$\sqrt{11}$	$\sqrt{127}$
RMS interference out of correlator (V)	$\sqrt{N_c}\sqrt{\sum^{\kappa N_c} L_i^2}$	$\sqrt{\sum^{\kappa} L_i^2}$	11	127
Avg. signal to RMS interference out of correlator	$\sqrt{E_s/(T_s \sum^{\kappa} L_i^2)}$	$\sqrt{E_s/(T_s \sum^{\kappa} L_i^2)}$	1	1
E_s/I_o improvement from spreading (dB)		0	0	0

8. Noise immunity vs spreading (cont..d).

M Incoherent Line Interferers in Band
(i.e., constant number independent of bandwidth)

$$L(t) = \sqrt{2}\sum^{M} L_i \cos(\omega_i t + \phi_i) \qquad \text{where } \omega_i/2\pi < B_c$$

Quantity	Formula or Nomenclature	$N_c = 1$ Base Case	$N_c = 11$ vs $N_c=1$	$N_c = 127$ vs $N_c=1$
Interference power into correlator (W)	$\sum^{M} L_i^2$	$\sum^{M} L_i^2$	1	1
RMS interference into correlator (V)	$\sqrt{\sum^{M} L_i^2}$	$\sqrt{\sum^{M} L_i^2}$	1	1
RMS interference out of correlator (V)	$\sqrt{N_c}\sqrt{\sum^{M} L_i^2}$	$\sqrt{\sum^{M} L_i^2}$	$\sqrt{11}$	$\sqrt{127}$
Avg. signal to RMS interference out of correlator	$\sqrt{N_c E_s/(T_s \sum^{M} L_i^2)}$	$\sqrt{E_s/(T_s \sum^{M} L_i^2)}$	$\sqrt{11}$	$\sqrt{127}$
E_s/I_o improvement from spreading (dB)		0	10.4	21

Single Impulse Interferer

$v(t) = K\,\delta(t)$

Energy from filter $2K^2 B_c = 2K^2 N_c / T_s$	$2K^2 N_c / T_s$	$2K^2 / T_s$	11	127
eak voltage from filter $2 K B_c$	$2K N_c / T_s$	$2K / T_s$	11	127
Peak signal to peak impulse voltage ratio into correlator (V/V)	$\sqrt{E_s T_s} / (2K N_c)$	$\sqrt{E_s T_s} / 2K$	1/11	1/127
Total improvement in clipping potential due to spreading		0	10.4	21
Avg. signal to clipped impulse out of correlator (V/V)				

8. Noise immunity vs spreading (cont..d).

Constant Power, Constant Chip Rate, Varying Symbol Rate

Quantity	Formula or Nomenclature	$N_c = 1$ Base Case	$N_c = 11$ vs $N_c=1$	$N_c = 127$ vs $N_c=1$
# chips/symbol	N_c	1	11	127
Chip period (s)	T_c	10^{-7}	1	1
Chip rate (chip/s)	$1/T_c$	10^{7}	1	1
Symbol period (s)	$T_s = N_c T_c$	10^{-7}	11	127
Symbol rate (symbol/s)	$N_s = 1/T_s$	10^{7}	1/11	1/127
Chip energy (J)	E_c	10^{-7}	1	1
Symbol energy (J)	$E_s = N_c E_c$	10^{-7}	11	127
Signal out of correlator (V)	$N_c \sqrt{E_c/T_c}$	$\sqrt{E_c/T_c}$	11	127
RMS noise into correlator (V)	$\sqrt{N_o/T_c}$	$\sqrt{N_o/T_c}$	1	1
RMS noise out of correlator (V)	$\sqrt{N_c}\sqrt{N_o/T_c}$	$\sqrt{N_o/T_c}$	$\sqrt{11}$	$\sqrt{127}$
Avg. signal to RMS Gaussian noise out of correlator	$\sqrt{N_c}\sqrt{E_c/N_o}$	$\sqrt{E_c/N_o}$	$\sqrt{11}$	$\sqrt{127}$
E_s/N_o improvement from spreading (dB)		0	10.4	21

Incoherent Line Interferers in Band
(i.e., constant number independent of bandwidth)

$L(t) = \sqrt{2} \sum L_i \cos(\omega_i t + \phi_i)$ where $\omega_i/2\pi < B_c$

Quantity	Formula or Nomenclature	$N_c = 1$ Base Case	$N_c = 11$ vs $N_c=1$	$N_c = 127$ vs $N_c=1$
Interference power into correlator (W)	$\sum L_i^2$	$\sum L_i^2$	1	1
RMS interference into correlator (V)	$\sqrt{\sum L_i^2}$	$\sqrt{\sum L_i^2}$	1	1
RMS interference out of correlator (V)	$\sqrt{N_c}\sqrt{\sum L_i^2}$	$\sqrt{\sum L_i^2}$	$\sqrt{11}$	$\sqrt{127}$
Avg. signal to RMS interference out of correlator	$\sqrt{N_c E_s/(T_s \sum L_i^2)}$	$\sqrt{E_s/(T_s \sum L_i^2)}$	$\sqrt{11}$	$\sqrt{127}$
E_s/I_o improvement from spreading (dB)		0	10.4	21

8. Noise immunity vs spreading (cont..d).

Single Impulse Interferer

Quantity	Formula or Nomenclature	$N_c = 1$ Base Case	$N_c = 11$ vs $N_c=1$	$N_c = 127$ vs $N_c=1$
$v(t) = K\,\delta(t)$				
Energy from filter $2K^2 B_c = 2K^2 / T_c$	$2K^2 / T_c$	$2K^2 / T_c$	1	1
Peak voltage from filter $2 K B_c$	$2K / T_c$	$2K / T_c$	1	1
Peak signal to peak impulse voltage ratio into correlator (V/V)	$\sqrt{E_c T_c} / (2K)$	$\sqrt{E_c T_c} / 2K$	1	1
Total improvement in clipping potential due to spreading		0	0	0
vg. signal to peak impulse out of correlator (V/V)	$\frac{N_c}{2K} \sqrt{E_c T_c}$	$\frac{1}{2K} \sqrt{E_c T_c}$	11	127
Improvement due to spreading (dB)		0	10.4	21

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