Everything has changed in publishing. In days of yore, there was much typing, cutting and pasting, typesetting, and proofing involved. Today, virtually everyone prepares their own typeset version of their paper. But something has been lost in the transition. There were many steps in earlier processes, but there were also many pairs of eyes involved in developing and polishing the final product. And so, over the last decade, we have seen a degradation in the quality of papers. I cannot go into much detail on the literary and logical thought process that goes into writing a good paper; that is largely self-taught anyway. I will, however, attempt to correct some of the pervasive deficiencies of form and style, whose responsibility, unlike in the past, now resides with the author. These problems are mostly mechanical in nature but also make it difficult for a reader to quickly assimilate the real information. Distractions matter, and it behooves us to minimize these as much as possible so that one can concentrate on the substance in a technical paper. Fortunately, this is rather easy to remedy if the writer is made aware of the conventions and traditions that have evolved over many decades.

I review many papers and am getting tired of harping on the same problems and issues over and over again for every new graduate that is (or should be) struggling to produce a readable and comprehensible paper as well as seasoned authors who should know better. I am hoping to ease the burden of the reader, who as William Strunk, in *The Elements of Style*, said, "... was in serious trouble most of the time, a man floundering in a swamp, and that it was the duty of anyone attempting to write English to drain this swamp quickly and get this man up on the ground, or at least throw him a rope." I am also hoping to instruct readers, so that in critically observing the writings of others they will also hopefully become better writers themselves, improving communication in the technical com-

munity. I should also mention the danger of being insensitive to such matters: you have to do it right the first time and always to form and retain your ability to see flaws.

Dos and Don'ts
of Technical Writing

After touching on some general proofreading principles, I will discuss some common errors of form and style found across all forms of technical writing, including internal reports, conference papers, journal articles, and books. Remember that good habits must be scrupulously followed from the lowest to highest forms of technical publication because insensitivity will lead to inconsistency and poor quality.

Dennis R. Morgan

Proofreading and checking equations

Equations used to be the bane of technical writing because the writer did not have direct control over the process. Thus, as the text was typed, retyped, and typeset, errors would inevitably creep in, and the author, having read over such equations many times, often overlooked such errors. Now the situation is vastly improved, as the author prepares his own equations in typeset form from the start, and thanks to modern electronic text processing, these do

not change from draft to draft. But of course now the responsibility of getting equations right with the proper form and style falls squarely on the shoulders of the author; there is very little help from others to "clean up" the presentation. So we have the advantage of consistency but also must recognize that if something is ugly it is going to stay ugly unless we fix it.

It is always a good idea when proofreading your draft (at least the first time) to look at what is written on the page and check whether what you say is actually true. For example, if the text says "substituting (10) and (12) into (5) gives (15)," then take pencil and paper and make sure that this does indeed produce the stated result. Don't rely on your previous notes because you may have made a mistake in transcribing the equation to the printed page. Likewise, if you have an equation that is to be numerically evaluated for values stated in the text, take out your calculator and, looking at what is printed on the page, verify that the stated numerical result is indeed obtained. All of this is a sanity check to make sure that what you are saying is actually true. You will be surprised at how many times that checking in this way will not produce the correct result! In discovering such

inconsistencies, you then go back and fix the typographical errors that have given rise to the error. In doing so, you are guaranteeing that the reader does not waste time trying to figure out why what you said doesn't make sense.

The upside is that once you have gone through this process for a particular passage of text and equations, you will never have to do it again, thanks to electronic text processing. (In the final publication process, equations sometimes have to be "tuned," so special vigilance is still required at this point; in this respect, the Latex math formatter is the most reliable and robust.)

One of the most useful features of text processing is the ability to electronically display the differences between a previous and current version of the text. This is extremely helpful in the late stages of production when you are tired of reading over the same thing so many times. If you have an ascii source file (e.g., Latex), this can be done using the Unix `diff` command; in Word, you can use the "Compare Documents" feature.

General writing

Author name: The author's first name should be spelled out, not abbreviated with an initial, so that readers know who you are. Author initials are only used in *citing* papers, not in the original paper itself!

Footnotes: Footnotes have been historically used for two purposes: 1) to elaborate on a statement, giving further details and/or references, and 2) to add material as an afterthought. The first is still warranted in some kinds of writing (e.g., literary or medical), although not usually appropriate for engineering publications because it is distracting, as the reader's gaze must shift to the footnote and then back to the text (engineers tend to read through all of the details!). In many cases, the details can be put right into the text, in parentheses, or if too long, in an appendix. The second purpose of footnotes, to add material as an afterthought, was historically used as a pragmatic expediency, as printed text was difficult to change. With modern text processing, this usage is totally obsolete because one can easily insert or delete text at will.

Quotation marks: In ordinary writing, use *double* quotes to quibble with the meaning of a word or give allegorical meaning. (Single quotes are for c-code and MATLAB and should be avoided in ordinary writing.) For example, one would say:

The "optimal" value of x here is rather elusive because there are competing objectives.

Note that any punctuation at the end of a quoted phrase is placed *before* the closing quotation mark, e.g.,

When he said "stop," he did not really mean it.

Do not use double quotes for defining words (see *Italics* below).

Capitalization: Don't capitalize generic phrases such as code-division multiple access (CDMA) or bit error rate (BER). Do capitalize phrases that are proper names such as Universal Mobile Telecommunications System (UMTS) and also words in phrases that are proper names like fast Fourier transform (FFT). Capitalize words referring to specific parts of the text, e.g., Section A, Figure 3, Table II, and Appendix C, as well as specific enumerated entities like User A, Receiver 1, and Algorithm I.

Italics: For emphasis of words, use italic font. Don't use underline; that convention is a carryover from old-fashioned typewriters, which didn't have font selection. Italic is also used to define new or unfamiliar terms, but not for terms that are (presumably) well known to most readers. Thus, use italics the first (and only first) time the new term is encountered, e.g., "We shall refer to this quantity as *backoff*, measured in decibels. For the above example, the backoff was set to –10 dB relative to the peak power."

Spacing: Always use a space between a number and its unit, e.g., 5 dB. However, if the quantity is used as an adjective, the number and its unit are hyphenated, e.g., 5-dB contours.

Hyphens and dashes: Use hyphens for compound adjectives, e.g., time-domain analysis. Note that a hyphen is not necessary with th, as in nth, or in other such constructions. Also note that a hyphen (-) is not a substitute for the dash. There are two kinds of dashes: a long (em) dash (—), which is used to set off a subordinate clause, and, a short (en) dash (–), which is used to express to, or through, as in a range of numbers, e.g., pp. 6–9.

Numerals: For numerals, use the words "one, two, ... , nine" for enumerating objects and "1, 2, ... , 9" for numerical values. Thus, e.g., write "We use two antennas in this configuration," but "We assume that x is greater than 1." For 10 and above, common publisher style uses numerals, e.g., "We use 25 antennas in this configuration." You'll

always want to follow the style of the publication for which you are writing.

Page numbers: Always number pages so that reviewers can refer to specifics in the text. This also aids in the final production, whereby the author can communicate with the publisher by reference to the original manuscript.

Word usage

Here we just mention some of the more common errors found in engineering journals. More general word usage rules can be found in *The Elements of Style*.

That and which: Use *that* in a defining relative clause and *which* for non-defining relative clauses:

The filter that has just been proved permits us . . .
This theorem, which was proved by Brown, permits us . . .

A simple test for defining clauses is to ask yourself the question "which one?" and if you can answer meaningfully, then use "that." For example, in the above, you ask "which filter?" and the answer is "the one that has just been proved," so use "that."

Can and may: Distinguish *can* and *may*:

According to (15), this expression can be written as . . .
Interested readers may request copies of the report . . .

Affect and effect: Distinguish between *affect* (to cause something to change) and *effect* (the result of some change).

Notice and note: Note that you *notice* someone walking down the street, but you *note* something that requires mental deduction, not merely observation. Thus, e.g., one says "Notice in Fig. 1 that the curves all converge as x increases," but "Note that in the above equation, the limiting value of $f(x)$ as $x \to \infty$ is $\pi/2$."

Notation, distortion, performance: In the context of defining mathematical symbols, the word notation is a collective noun and does not use an "s" on the end. Thus, one says, e.g., "The notation used in this paper is summarized in Table I." In ordinary usage, the plural form "notations" is sometimes used, as in, e.g., "Examination of Newton's original text shows several notations in the margins dealing with special cases." The words "distortion" and "performance" are almost always used in the singular collective sense.

e.g. and i.e.: When using the expressions e.g. ("for example") and i.e. ("that

is"), note that a comma should always be used *before and after* the expression, except when used to start a parenthetical comment, in which case the initial comma is omitted. (An exception for the case when these are used at the beginning of a sentence is not necessary because such usage is to be avoided.)

Jargon: Avoid technical jargon that combines words to make up new words that are not in the dictionary (e.g., pathloss, basestation, etc.). A good way to test for current accepted usage is to search journal article titles in an electronic database, such as IEEE *Xplore*. (Limiting the search to titles in journal articles obtains the most reliable results since many people in the production of a paper at least look at the title.)

Conclusions: The final section of a paper should be titled "Conclusions" not "Conclusion;" you are not concluding the paper, you are giving your conclusions of the study, which is a different usage of the word.

Mathematics

Starting sentences: Don't start a sentence with a math symbol. It slows down the reader because the beginning of a sentence is signaled by an initial capitalized ordinary word. So when a math symbol is the subject of a sentence, preface it with something like "Here, ..." or "In this case, ...".

Font style: Use italic font for all ordinary (single-character) math variables, e.g., x, y. Although it is never a good idea to use more than one character for a math variable, if you insist on using something like SNR (signal-to-noise ratio), use a roman font because math italic SNR will not be spaced properly and moreover can be misinterpreted as the product of three variables, $S \times N \times R$.

Font size: Use one consistent font size throughout for the principal part of all math symbols, with consistent reduced font size for subscripts and superscripts. (Latex does all of these things, and more, automatically.)

Bold fonts: Authors should consider using a bold font for vectors (lower case) and matrices (upper case) because, unlike in the past, we have ready access to this option, and most technical writers of journal articles and books currently adopt this convention. Again, it helps readers if a common language is established so they can concentrate on the substance of the paper without the distraction of having to figure out what is meant by strange and unfamiliar notation. Furthermore, although scalar math variables are traditionally italicized, it is preferable to use bold roman instead of bold italic for vectors and matrices; it is less confusing, and most books and journals, the American Institute of Physics, and many other publishers now use bold roman.

Abbreviations: Ordinary words or abbreviations of words in mathematical symbols, particularly subscripts, should be in roman, not italic, font, so that they are not misinterpreted as math symbols themselves. For example, write x_i (italic i) for the ith component of a vector $\mathbf{x}$ because i is a math variable, but write x_{i} (roman i) to denote a variable x measured at the input (i here is an abbreviation of "input" and is not a math variable). Likewise, write $y_{\min}$, y^{opt}, etc. Also, when units like "dB" are included in mathematical expressions, special care must be taken to render them in roman, not italic, font ("d" and "B" are not math variables here!)

Functions and operators: Note that math functions of more than one character like sin( ), cos( ), exp( ), log( ), and max( ) should be roman font, not italic, to distinguish them from a product of ordinary math variables (e.g., $sin = s \times i \times n$). Although a contravening argument can be made, operators like expectation E and the transpose superscript $( )^T$ are by and large rendered in italic font, which is perhaps for the better to avoid possible confusion with (roman) abbreviations of words.

Superscripts: If $\mathbf{x}(n)$ is a vector sequence, write $\mathbf{x}^T(n)$, not $\mathbf{x}(n)^T$ for the transpose. Likewise, for a scalar sequence $x(n)$, the square is written $x^2(n)$, not $x(n)^2$. Note that superscripts and subscripts should be horizontally aligned, one directly above the other, e.g., write x_n^2, not $x_n{}^2$. In general, avoid numerical superscript indexes, which can be confused with ordinary exponents. If you must use such indexes, write, e.g., $x_n^{(2)}$ to denote the index, not x_n^2, which looks like the square of x_n

Minus signs: Use a minus sign (−) not a hyphen (-) in math expressions, e.g., $x - y$. Displayed equations with math formatters like Latex automatically do this, but particular attention must be paid to inline text. (It is good practice to always use the math format mode to enter in-text math.) Also, use the minus sign for inline numerical quantities, e.g., −10 dB. Also take care to follow these rules for figures, especially block diagrams.

Spacing: Use a space before and after +, −, =, e.g., $1 + 2 = 3$. Also, use proper spacing for arrays, viz., $[\, x_1 \quad x_2 \quad \cdots \quad x_N \,]$.

Fractions: Don't let the point size reduce for fractions in displayed equations. In Latex, the font size of fractions in displayed equations will occasionally reduce in font size, which is undesirable. To remedy this use \dfrac: \newcommand{\dfrac}[2]{\frac{\displaystyle#1}{\displaystyle#2}}. Inline math fractions that appear in the text should be written as x/y rather than $\frac{x}{y}$ to maintain consistent font size and avoid inconsistent spacing between lines of text.

Nested parentheses: Nested parentheses (()) should be avoided, preferring the standard hierarchy {[()]} instead. MATLAB doesn't have trouble interpreting nested parentheses, but humans do. The eye wants to parse a mathematical expression to distinguish the various orders of suboperations. That is why the standard mathematical hierarchy is traditionally used: to help the reader assimilate the meaning of the expression.

Punctuation: Equations, like text, should be properly punctuated so that the reader knows when to stop, when to pause, and when to read on. Therefore, if an equation is at the end of a sentence, put a period at the end. If the sentence continues on after the equation and grammatically calls for a pause, you can optionally put a comma at the end of the equation, although some writers consider this unnecessary because the interjection of a displayed equation (without a comma at the end) automatically suggests a pause (some IEEE transactions adopt this point of view).

Definitions: Always define new terms and variables where they are first introduced and not several sentences, paragraphs, or even pages later. There is nothing more frustrating to a reader than the introduction of undefined terms. Also, don't bury important definitions in the text; make them stand-alone, displayed equations so that a reader can quickly find and refer back to them.

Numbering: In most cases, don't number a collection of N quantities as $n = 0, 1, \ldots, N - 1$, since it is quite unnatural to count items starting with zero. Therefore, a collection of N quantities should usually be designated as $n = 1, 2, \ldots, N$. The exception is for digital number representations, DFT/FFT constructions, and the like, where starting with zero makes sense.

Some common errors of IEEE Transactions authors

Section numbers: In IEEE journals and transactions, use IEEE-style section numbering,., I, II, ... , etc. for major section headings, A, B, ... , etc. for subsections, and 1, 2, ... , etc. for subsubsections. Much of this is done automatically when using IEEE templates.

Figures: The word "Figure(s)" is abbreviated as "Fig(s)." Put the entire caption below the figure. If there are subplots, label them as (a), (b), etc., and put the description of these in the main caption. Don't use the same caption for two different figures. Avoid repetition, but include as much detail as necessary to distinguish figures. In general, keep figure captions short, relying on the text to give context, relevance, and verbose detail.

References: Standard IEEE citation of references is [1], [2] and [3]–[5], *not* [1,2] and [3–5], respectively. If a certain page number or chapter is being cited, write as, e.g., [1, p. 7] or [2, ch. 3]. IEEE style requires references to be listed numerically in the order of their citation, [1], [2], etc.. Most other journals also follow this practice, which has several advantages. First, the reader can follow the citations much easier if they are cited in order because one then doesn't have to go jumping through the reference listing in random order. Second, if one sees a particular familiar work in the reference listing, it can be easily located in the text to see how it is specifically relevant to the present work. Finally, it serves as a check to make sure you have cited all of the references in the list, which is difficult to do if not cited in order. The alternative is to alphabetically order the reference listing with respect to the principle author's last name. Although a few journals have adopted this practice (e.g., *Elsevier Signal Processing* and some past ICASSP proceedings), the practice is arguably inferior, the only exception being possibly for a survey-type article or textbook that has a large number of references, say, 100 or more.

Use correct IEEE reference style (see IEEE's Information for Authors or any IEEE journal). For multiple authors, use the form "Author1 and Author2" or "Author1, Author2, and Author3" (note the final comma and the word "and"). Only capitalize the first word of article titles for journals and conference papers, using double quotes before the first word and *following* a comma after the last word. For journal articles, properly abbreviate the journal title, use "vol." and "no." (no capitals), give page numbers as "pp.," and abbreviate the month, e.g., Jan., Feb. For conference proceedings, put "in *Proc.*" before the conference title and include page numbers *after* the year (like for a book).

Conclusions

All of the forgoing discussion is predicated on the current state of the art in electronic text processing. In the future, some of the details may require modification or be rendered obsolete as the technology progresses. Nevertheless, the basic principles and goal will remain unchanged, that of producing literate, consistent, and readily comprehensible technical writing.

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Read more about it

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