What is RF?

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Speaker's Corner

What Is RF?

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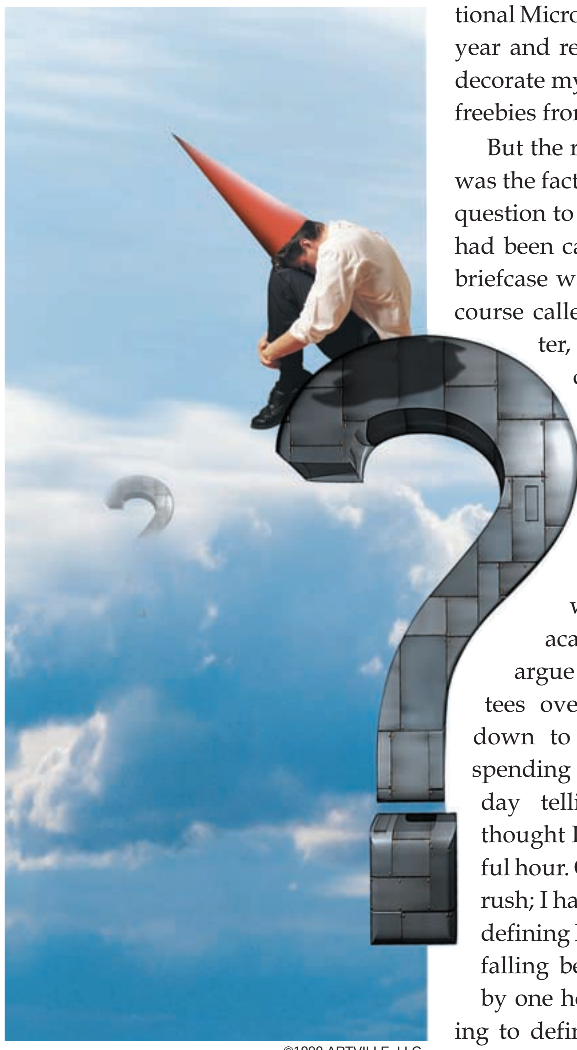
It was bound to happen. For weeks I had been bringing home a book or two with titles such as *RF Design* or *RF Circuits*. My son, who is an avid reader, keeps a watchful eye on my briefcase and takes more interest in what I am reading than I do in what he is reading—I suppose to protect me from subversive or trashy books. He noticed the books in my briefcase, so he asked me the obvious question, "What is RF?"

It is not often that I am speechless, particularly on a subject that I am supposed to be an expert on. Many thoughts crossed my mind as I considered what would be an appropriate response. Should I give a terse response, mentioning the two words that the abbreviation RF stands for? Or, should I take advantage of this opportunity to indoctrinate my son in my profession and instill in him the pride of having a father working at the cutting edge of technology? Or perhaps a mini-lecture, for which I am famous among my children? It would probably not be a good idea to tell him the facts of life and cry about how the word *microwave*, being currently out of fashion, is being replaced by RF. After all, he still thinks microwave is an honorable profession; he has watched me go to the annual International Microwave Symposium year after year and return with thick volumes to decorate my bookshelf – not to mention freebies from the exhibits.



But the real reason for my hesitation was the fact I knew this was not an easy question to answer. In fact, the reason I had been carrying the RF books in my briefcase was because I was teaching a course called "RF Design" that semester, and on the first day of classes I got trapped into defining RF for my students. I felt the students deserved to know the meaning of the phrase appearing in the course title. Although I would not want to divulge this to the academic bean-counters who argue in the curriculum committees over the content of a course down to each lecture, I ended up spending the entire hour on the first day telling my students what I thought RF meant. That was a stressful hour. On the one hand, I wanted to rush; I had not planned to spend time defining RF and doing so meant I was falling behind in my course outline by one hour. On the other hand, trying to define RF was like getting into quicksand; the more I explained, the more I realized how complex a task I

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had unwittingly undertaken, and recognizing that my comments must appear cryptic to my uninitiated students resulted in even more elaboration. It reminded me of press briefings held to explain the previously given explanations. Thank goodness for the class bell.

Historical Basis of Definition

So just exactly what does RF mean? We all know that RF is an abbreviation for radio frequency. Although it can be used as a noun (as in, "RF is King!"), it is mostly used as a qualifier: RF circuit, RF engineer, RF interference, RF spectrum, etc. If RF is primarily a qualifier, then its purpose is to distinguish things that are RF from those that are not. So what distinguishing features or characteristics does this qualifier imply? The answer to that question keeps shifting with time due to the changes in technology. For example, once upon a time, an amplifier made with electron tubes would qualify as an RF amplifier if its pass-band extended above 600 kHz into the "radio" broadcast band. Today, an operational amplifier having a pass-band from dc to 2 GHz, is called an analog, rather than an RF, component. There seem to be several bases on which the distinction between RF and other objects has been based in the past, each with its own shortcoming. Here are some of them.

Bandwidth-Based Definition

The venerable "bible" of a generation of radio engineers from a half century ago, Fredric E. Terman's *Electronic and Radio Engineers*, treats RF amplifiers as synonymous with tuned amplifiers. The implication is that RF circuits are necessarily narrowband circuits, having bandwidths that are a small fraction of the center frequency. Conversely, broadband circuits would not qualify as RF. Such a definition would not pass muster today; we routinely design circuits with multidecade frequency pass-bands. Indeed, increasing the bandwidth of your RF design would carry with it the risk that the design would no longer remain RF!

Frequency-Based Definition

Sometimes, handbooks define RF as the range of electromagnetic waves lying between the low-frequency bands (LF and below) and the microwave frequency bands (UHF and above), thus encompassing the CCIR-designated bands MF (300 kHz - 3 MHz), HF (3 Mz - 30 MHz), and VHF (30 MHz - 300 MHz). This is the frequency range that the microwave engineers of earlier years condescendingly referred to as "dc." Given that the integrated circuits in the UHF region are now routinely called RFICs, we may have to shift the UHF band out of the microwave basket and add it to the RF group. How times have changed! I personally knew some of the practitioners of that high art form called microwave engineering who proudly declared themselves to be "microwave plumbers" and would have been offended if someone had called them a mere "RF engineer."

Application-Based Definition

Communication system engineers sometimes distinguish RF from other frequency ranges on the basis of the role in which the signals at those frequencies serve. Historically, RF signals were not "information" but were used as carriers of the information-bearing signals in radio broadcasting and other radio (i.e., wireless) applications. By tradition, in the AM radio band (where actual information-bearing signals extend from approximately 50 Hz to 6 kHz), a preamplifier that extends from 600 to 1600 kHz would be considered an RF amplifier because it operates on the carrier signals in that frequency range. On the other hand, a video amplifier having a pass-band from 50 Hz to 6 MHz is not an RF amplifier because the information-bearing video signal itself occupies that frequency range. Since most information-bearing signals start out at base-band, this definition makes the qualifier RF almost an antonym of the qualifier "base-band." There are many problems with this definition, of course. For example, optical signals are used as carriers too, but the practice of referring to them as RF has not become widespread, at least as yet. Then there is the problem that some information-bearing signals are not base-band, and many a digital information-bearing signal may contain frequency components extending all the way up to the carrier frequency.

Size-Based Definition

An object (component, circuit, module, product, etc.) used to process electronic signals is sometimes defined as being RF provided the phase-shift of that signal, occurring over the extent of that object, is not negligible. This is equivalent to the assertion that, for RF hardware, size is not negligible compared to the wavelength of the electromagnetic (EM) waves that they processes. However, this definition of RF elements appears to be synonymous with that of distributed circuit elements and leaves the so-called "lumped RF components," such as chip capacitors and spiral inductors, in a precarious position. There are also several other difficulties with it: should we compare the wavelength with the size of the entire system, or the smallest critical dimension in it; what if the size is much larger than the wavelength (at the optical end of the spectrum); what about the use of the qualifier RF for nontangible items, such as RF software, RF data, RF methodology, etc., that have no inherent "size" of their own, or that may be applicable for designing objects having a variety of sizes.

Finding a Consistent Basis for Definition

It is clear that the historical definitions of RF are no longer adequate. However, current usage is no more logical or consistent. We find the phrase being used to convey more than one sense. On the one hand, the qualifier RF is frequently used to refer to the frequency range lying just below the microwave frequency range. This use is inconsistent with the use of the term RFIC for integrated circuits operating at millimeter and submillimeter wave frequencies. On the other hand, we find the phrase RF being used in the literature to refer to signals ranging in frequency from the AM broadcast band to the submillimeter wave and even infrared (IR) region. But if that is accepted, RF includes the microwave region as a subset and the wildly popular phrase "RF and microwave" is meaningless.

The widespread use of the phrase "RF and microwaves" is problematic in itself. I can think of several reasons for its current popularity.

- *Fuzzy Thinking.* Today, we sometimes use the phrase "RF and microwave" the way laymen use the phrase "science and technology"—as if they were one and the same. Maybe we are just too lazy to think precisely and choose the appropriate word. A fuzzy phrase serves us well. Often it is used where we would have used the term microwave in an earlier era.
- *Glamorous Association.* Popular press has glamorized the term RF by calling it one of the most promising commercial technologies of the decade, which gives it the image of being an up-to-the-minute, exciting field. By contrast, microwaves are an "established" (read "older") technology that has a historical association with military work and a cyclical nature of marketability. So an association with RF makes microwaves more respectable.
- *Political Correctness.* As a result of the current trend of political correctness that has crept into our language, we constantly try to be all-inclusive. The phrase "RF and microwave" clearly has a wider scope and meets this subconscious need.
- *Pompous Writing.* Lawyers are known to routinely add a lot of near-synonymous words to important phrases, in an attempt to make a document air-tight—for example, cease and desist; covenants, conditions, and restrictions; as amended, revised, modified, or supplemented; and sell, exchange, transfer, or otherwise dispose. Of course, the resulting legalese is known to be stuffy and formal, but others have copied this habit for emphasis or simply to make their writing appear important. The phrase "RF and microwave" has this ring of being a well-considered, profound term.

It seems that the question, "What is RF?" cannot be satisfactorily answered by an etymological or historical analysis of the name RF. Such an analysis would only show that it is the incessant advancement of technology that makes it hard for us to define the qualifier RF. Point out a precise boundary line to a creative engineer, and he/she will find a way to make it fuzzy by inventing objects that straddle the boundary. Once we recognize technology as the culprit that makes definitions imprecise, we might also look to it for guidance. Like technology itself, the meaning of the qualifier RF changes with time, and like many other technological ideas, it is a concept whose understanding requires a familiarity with the technology to which it relates. In fact, the most rational basis for defining RF, and one that evolves with time to stay forever current, may be based on the distinguishing features of the RF technology itself. Then, RF refers to a way of looking at the world that is somehow distinct from audio, video, optical, and various other world views.

Distinguishing Features of RF

What confers upon a component a membership in the RF class? It seems that the distinction between the RF and the non-RF objects arises from the different design considerations that required the attention of their designers. RF designs need attention to some (or several) of the following

- *Phase Shift.* Concern with signal phase shift over the extent of the component caused by a component size that is nonnegligible compared to wavelength. This concern manifests itself through the use of
  - compact designs, so as to minimize unintended phase-shifts
  - explicit accounting and utilization of phase shift due to propagation delays
  - distributed (i.e., transmission-line) models for circuit elements.
- *Reactances.* Concern with presence of nonnegligible parasitic (i.e., unintended) reactive (i.e., energy-storing) elements and its various consequences, such as resonances.
- *Dissipation.* Concern with signal dissipation in the circuit, not merely due to the resulting loss of signal power, but primarily due to its impact on
  - frequency selectivity, or Q, in a narrow-band operation
  - thermal noise generated in dissipative elements.
- *Noise.* Concern with internally generated noise, which tends to dominate over other external sources of noise—both natural and man-made—in the RF range.
- *Radiation.* Concern with electromagnetic radiation of energy from the circuit, either
  - for minimizing the unintentional radiation of energy, (e.g., to reduce unwanted coupling)
  - for enhancing the effectiveness of intentional radiation (typically by incorporating radiating structures).
- *Reflections.* Concern with impedance matching, primarily for minimizing the resulting reflections, rather than the resulting loss of transferred power.
- *Nonlinearity.* Concern with nonlinearity in the context of frequency translation and spurious generation.

It seems RF will remain a popular phrase for some time to come. Components and circuits whose design share a number of these concerns are RF, regardless of the numerical value of the frequency or bandwidth of electromagnetic signals involved. With a definition based on the designers' mind-set, we can include many kinds of components under the umbrella of RF at virtually any frequency from LF to IR. How's that for all-inclusive, politically correct terminology?