PHANTOM SOUNDS

By WAYNE BARLOW

IT has been suggested in some quarters (see *Radio-Craft* for February, 1943) that the problem of re-creating a satisfactory illusion of reality in reproduced music, a problem essentially one of adequate frequency response and fidelity, be approached on the basis of extending the frequency spectrum at both ends by strengthening the subjective tones that form a part of normal auditory phenomena. It is the purpose of this article to examine the proposal and to point out certain fallacies in the proposed application of this method to radio broadcasting.

Briefly, a subjective tone is one that is perceived by the listener as a tone of a definite frequency; this frequency, however, is not present in the auditory stimulus that produces the illusion. The existence of such tones has been known to musicians and acousticians for two hundred years, yet their existence cannot be proven scientifically or otherwise analyzed. The most readily perceived subjective tones are those that are known collectively as *combination tones* and take the form of an illusion of a third frequency when two tones of different frequencies are heard. One such tone, the *difference tone,* will be heard as a frequency equal to the difference of the frequencies of the generating sounds; another, the *summation tone,* will be heard as a frequency equal to their sum. (Radiomen will realize that these "beats" are no illusion, and their existence is readily proved, for example by inserting a meter in the audio circuit and watching the periodic swing of the pointer.—*Editor.)*

A better example is the one that is perceived as the fundamental of a series of overtones. As an illustration of this type of tone, let us suppose that a complex wave form, such as might be generated by a musical instrument having a fundamental frequency of 220 c/s and upper partials of 440, 660, 880, 1100, and 1320, is fed into an audio amplifier. If a high-pass filter with a cut-off frequency of 300 cycles is introduced into the circuit, the ear will still hear the fundamental frequency even though it has been entirely suppressed. It will be noted that the difference in frequency between adjacent partials in every case is 220; therefore, it must be assumed that the perception of the fundamental is a function of the difference tone provided by one or more pairs of upper partials.

The practical aspect of this phenomenon is observed in the case of the ordinary telephone installation, in which the lower cut-off frequency is of the order of 300 cycles. The fundamental pitches of the speaking voices of men and women average roughly 128 and 256 cycles, respectively, yet these suppressed pitches are apparently heard. Likewise, reception on a midget radio receiver, where the low frequency response may be but little better than that of the telephone receiver, is such as to provide the illusion of a certain amount of bass.

So far as summation tones are concerned, there is little evidence that their contribution to the auditory experience is of any importance; the perception of such tones is difficult, even for a trained ear, and it can

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The fantastic musical instruments illustrated here never existed, but distortion has brought them to us on many programs. The discriminating listener will recognize, reading from top down, the ACCORDORGAN, the GUITAHARP, the SOUSADRUM, the KETTLEVIOL and the CELLOSAX.

Photographs courtesy Pilot Radio Corporation

The above series of illustrations show how the destruction of overtones makes one instrument sound like another, or like a blend of two.

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safely be assumed that they have a negligible effect in extending the frequency spectrum upward.

Recent research in the physiology of hearing has led to general acceptance of a theory of subjective tones based upon the response of the tympanic membrane (eardrum) to auditory stimuli. It is probable that the vibration of the membrane is symmetrical only for sounds of a low order of intensity owing to the damping effect of the *ossicles* (small bones in the middle ear) in transmitting the vibration to the inner ear. Thus the ear mechanism exhibits a non-linear response to sounds above a few decibels in loudness, the degree of non-linearity or distortion being proportional to the intensity. It has been demonstrated mathematically and corroborated by experience that the distortion of sound results in the presentation of a somewhat different complex of overtones than that present in the original stimulus. A sine wave greatly amplified would be heard as a fundamental plus a series of overtones, a distortion introduced by the ear mechanism. It seems fairly conclusive that certain difference tones as well can be explained on the basis of the non-linear response of the ear, an assumption borne out by the fact that the apparent loudness of these tones is in direct ratio to the intensity of the generating sounds.

An additional factor that must be taken into consideration is the marked insensitivity of the ear to sounds of low frequency, and a similar falling off in sensitivity to frequencies above 5,000 cycles. Curves adopted by the American Standards Association show that the energy in a 30-cycle tone required to make the tone just audible is more than a million times that required by a 1000-cycle reference tone at the threshold of hearing. Stated in another way, the 1000-cycle reference tone has an intensity of 0 decibels at the threshold, while the 30-cycle tone must have an intensity of over 60 decibels in order to be heard.

With the foregoing factor in mind it is possible to examine with some degree of objectivity the proposal referred to at the beginning of this article. As mentioned above, we may discount the importance of summation tones as a negligible factor in extending high frequency perception. The question, then, is whether or not the proposal to strengthen the impression of low frequency subjective tones by artificial means applied at the broadcast transmitter is fundamentally sound, assuming that the broadcast receiver is not changed as to its frequency response.

Since the perception of such tones depends upon the presence of upper partials in a harmonic relationship (2 × fundamental frequency, 3f, 4f, ... etc.) so that the fundamental will be reinforced (or *supplied* in the case of a receiver lacking in bass response) by difference tones, and since the apparent loudness of these tones varies in relation to the intensity of the generating sound, it is obvious that any apparent reinforcement must be accomplished by increasing the intensity of upper partials. We may rule out the strengthening of the entire spectrum as accomplishing nothing that cannot be achieved by turning up the volume of the receiver. It will be shown that the only remaining possibility, that of strengthening a selected band of frequencies, presents such serious consequences as to make application totally inadmissible.

A study of the frequency spectra of various orchestral instruments shows that each one possesses its own characteristic pattern of overtones, differing from others in both the number of overtones present and relative degrees of intensity. It is this characteristic pattern of overtones that lends to each instrument its individual tone quality (disregarding the formant theory of timbre): It is immediately apparent, then, that the artificial reinforcement of any block of frequencies would result in serious harmonic distortion to the extent that the characteristic timbre of instruments would be radically altered in reproduction, and the tone quality of the same instrument would differ according to register as the relation changed between the fundamental tone and the artificially reinforced overtones.

The reproduction of low register percussion instruments of indefinite pitch, such as the deep gong and the bass drum, presents a serious problem in equipment with *(Cont. on following page)*

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an attenuated low frequency response. Since these instruments are of indefinite pitch, the tone produced does not present a series of overtones in a simple harmonic ratio; for this reason a subjective impression of the characteristic low-frequency component is impossible in the absence of fixed pitches that might provide a difference tone. Reproduced through inadequate equipment, sufficient middle and high frequency sounds associated with the tone production of such instruments come through to make recognition possible, but the fundamental low-frequency characteristic is entirely lost. In this case no amount of harmonic reinforcement will strengthen a subjective impression that is absent to begin with.

Finally, the original premise on which the proposal under discussion is based, namely, that subjective tones can furnish a satisfactory substitute for objective ones, is open to serious question. At this point the trade statistics must be reckoned with, for, considering the number of midget radio receivers that are in the hands of listeners, quite a proportion of the listening public is apparently satisfied with a radically abbreviated frequency spectrum. While the situation is harmless enough in speech reproduction, one wonders whether this group knows what it is missing when it comes to music. It is not the purpose of this article to launch a discussion of public indifference to wide-range fidelity, but it would seem possible that a simple side-by-side test of music reproduced on a sawed-off spectrum, and then through equipment of even moderate fidelity, might convince some radio listeners that there is sometimes "more than meets the ear." A test of this kind offers, in most cases, the only means of making apparent the tendency of the human ear to adjust itself to and accept any kind of sound reproduction, no matter how inadequate.

It has been indicated that summation tones contribute little or nothing in the way of providing an illusion of high-frequency tones that are weak or absent in reproduction. Yet an adequate response in this region of the spectrum is just as essential to naturalness of music as good low-frequency output. Without it, instruments of the woodwind group in particular tend to lose their characteristic timbre in the upper registers as the strength of the overtones falls off. Certain percussion instruments also, such as the suspended cymbal and glockenspiel, suffer greatly from an attenuated high-frequency response because of the large concentration of energy in the high register. The most immediately apparent result of insufficient highs in reproduction is, of course, an overall lack of crispness, plus the destruction of "auditory perspective," or "extensity," both terms referring to the illusion of music occupying "auditory space." This latter is an important attribute of listening not usually taken into consideration.

The current interest in frequency modulation transmission has served to emphasize the inadequacy of amplitude modulated broadcasting, both in frequency range and in dynamic range from soft to loud. It is the author's hope that the wide development of FM network transmission, divorced from the limitations of wire lines, will prove economically feasible in the immediate post-war period, since at the present writing, it is the one system ready for immediate application that offers a wide-range audio channel to the radio listener.

(Author's note: The item in *Radio-Craft* referred to at the beginning of the foregoing discussion gave the figure 5000 cycles as the upper limit of hearing. This was an error, the limit being much higher, some figure around 15,000 cycles usually being given. The author has made informal tests with an accurately calibrated beat-frequency oscillator, and has found that the upper limit fell in most cases between 12 Kc. and 17 Kc.)

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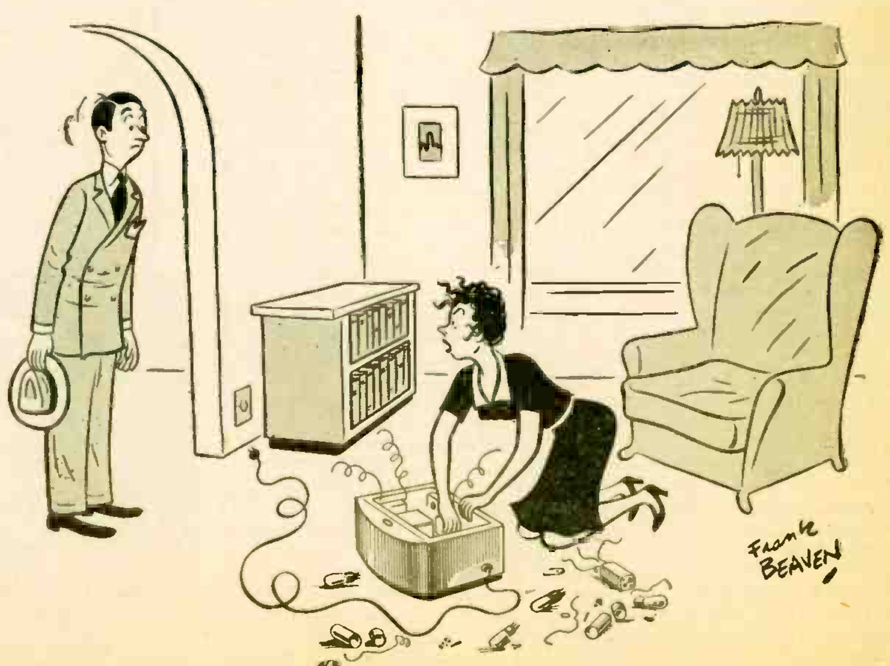
Plans have been completed for the erection of a government television transmitting station atop Mount Royal in Montreal. Work on the transmitter will begin as soon as materials become available. G. W. Olive, chief engineer of the Canadian Broadcasting Company, predicted that most of Canada should have video facilities within the next decade. Research into suitable programming has already been started and no time will be lost in launching the station once equipment is available, it was stated.



Suggested by Marguerite Muchmore, Encinitas, Calif.

"I'm trying to locate the bobby-pin you fixed this radio with six weeks ago."