The Lenkurt® Demodulator

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Signaling in Carrier Channels

Considering the simplicity of the functions performed by signaling in a communications network, it is surprising that they are accomplished in so many ways. Although these jobs are simple, they are most vital to the basic operation of the network.

In carrier systems, the methods by which supervisory signals are achieved have an important effect on the quality of transmission and the cost of the equipment. This article reviews some of these fundamental considerations of carrier signaling.

Signaling provides the "nervous system" of the communications network — reporting needs and bringing response. It coordinates the various parts so that they can operate together. Signaling provides the means for managing and supervising the communications system; it establishes connections, helps select the route (when there is a choice), announces the incoming call, reports the fact if a line is busy. Without signaling, the system could not operate.

Signaling can be done in many ways. The body sets up separate networks of nerves, completely independent of those which report the senses and direct the muscles. Some communications systems do the same, using separate channels to convey information used in controlling the operation of others. More often, however, it is more economical and much more flexible if each channel carries its own signaling. In local (physical or metallic) telephone circuits, this can be achieved by direct currents which share the line with the signal voltages. In multi-channel carrier transmission, however, different techniques are required. Voice channels customarily occupy a bandwidth of 4 kc. Some of this bandwidth is used for isolation from adjacent channels. The rest, usually about 3700 cycles, must carry both speech and signaling. In some cases, this channel bandwidth is used not only for voice, but also for one or more telegraph or teletypewriter circuits — so-called "speech-plus." In such cases, channel filters must be designed to prevent mutual interference between the speech, telegraph, and supervisory signals which share the channel.

Despite its importance, supervisory signaling has very little information content. Most signaling operations occur in establishing a connection, and at the end of the call. Generally, no signaling functions are required during the conversation itself (except that of maintaining the connection). This fact makes possible one of the most important signaling methods.

In most carrier systems, one of three basic methods may be used for signaling: "in-band", "out-of-band", or "separate-channel" signaling. In general, separate-channel signaling is only used on very high density "backbone" routes or under special circumstances where signaling cannot be conveniently handled with the communications channels themselves. Such an application is found in certain submarine cables where "TASI" (Time Assignment Speech Interpolation) is used to squeeze extra channel capacity from the idle time present in most voice communications. (For a more detailed description of TASI, see DEMODULATOR, August, 1961.) Although separate channel signaling has the advantage of leaving the entire voice channel free for communications, without the possibility of mutual interference between the speech and signaling, it is rather uneconomical since it requires that certain channels be set aside to handle only signaling functions. In addition, repair and maintenance is more complicated when signaling and speech are sent over separate channels. Reliability may be less since both channels are subject to failure independently of each other.

The two most widely used signaling methods are the so-called *in-band* and *out-of-band* methods. With out-of-band signaling, channel filters are designed with an upper cutoff frequency well below the top edge of the channel. This leaves a portion of the spectrum free to transmit signaling tones. Generally, a single tone is used and this is keyed to convey signaling information.

Some equipment takes advantage of the existence of a separate signaling channel above the voice frequency portion to perform other functions. In the Lenkurt 45-class equipment, for example, *two* tones can be used. Signaling information is transmitted by alternations between the two tones. Since one or the other of the two tones is always present, it becomes possible to use the signaling tone as a reference pilot for regulating the individual channel level.

By completely separating signaling from the speech portion of the channel, it is possible to maintain relative freedom from mutual interference between the speech and the signaling tones; signaling tones can be transmitted during the conversation, thus permitting extra functions such as regulation, which might be desirable during the period the speech channel is in use.

In addition to being more flexible, out-of-band signaling can be much easier and more economical to accomplish, particularly if some sacrifice in

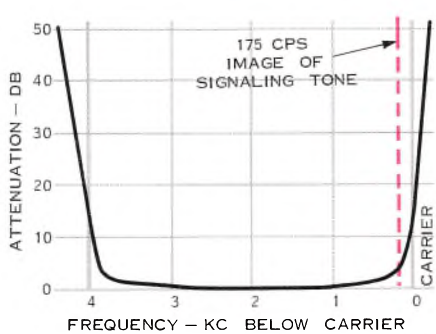


Figure 1. Typical carrier channel band-pass characteristic. Note that 175-cycle image tone, shown in solid red, is attenuated about 45 db.

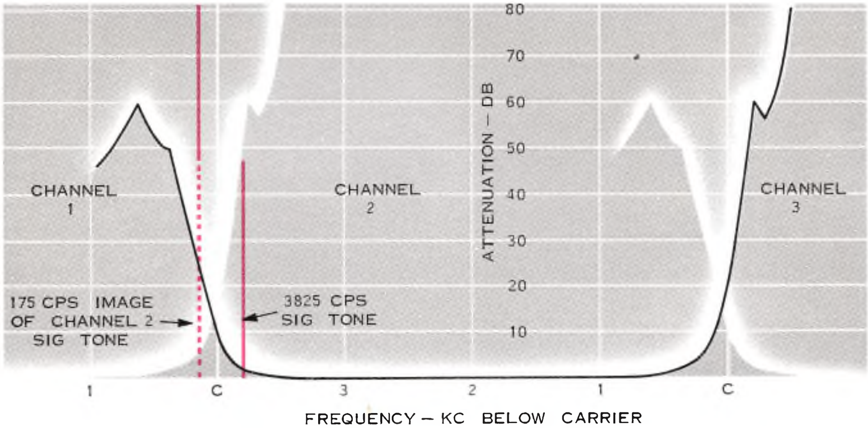


Figure 2. Relative response and attenuation characteristics of three adjacent SSB channels spaced 4 kc apart. When 3825-cps signaling is demodulated, images fall in adjacent channel at 175 cps. When transmitting, upper sideband images of 175-cps speech components could cause false signaling if inadequately filtered.

channel bandwidth is allowed. In telephone circuits, there is very little speech energy present at the upper end of the channel. Accordingly, filtering requirements may be somewhat relaxed (since telephone instrument weighting also provides a degree of "filtering"). This makes it possible to provide good quality transmission for relatively little equipment cost, since the greatest cost of carrier systems is in the channel filters. In general, efforts to increase bandwidth by approaching the channel edges more closely increases the cost of the carrier equipment.

Optimum Design

A careful compromise between speech quality and equipment cost is required. If the out-of-band signaling tone is too low in frequency, the restriction on bandwidth may impair speech quality. If the signaling tone is raised in frequency so that it lies close to the top edge of the 4-kc band, channel filters must be made more complex.

A case in point is the use of a signaling frequency of 3825 cycles per second, standard in many countries. Where channel filters are not sufficiently effective, a 3825-cps signaling tone appears as a 175-cps tone in the adjacent channel, but at a fairly low level. This results from the fact that the 3825-cycle tone falls at the same frequency as the "image" or unused sideband of a 175-cps tone in the adjacent channel. Although filters essentially eliminate this sideband, even the best channel filter characteristics are far from ideal. Figure 1 shows typical attenuation characteristics. Note that although the 175-cps component from the next channel can appear following demodulation, it is attenuated about 45 db. Although attenuated to a low level, the tone may still be audible and disturbing. In such cases, it is necessary to provide additional filtering following the demodulator in order to eliminate the tone.

Conversely, if a high-pass 175-cps filter is not used prior to modulation, speech energy at this frequency may appear as 3825-cycle energy in the adjacent channel, thus causing false signaling. In order to attenuate the 175-cps component adequately with conventional filters, the low frequency channel cutoff is approximately 300 cps. In accordance with conventional practice, the high frequency cutoff remains at approximately 3400 cps. Although this frequency range provides acceptable performance over most communications circuits existing today, longer circuits would be excessively degraded. For instance, current CCITT* Standards call for a 2500 kilometer hypothetical path with 3 audio drops or links. At present, new standards are being prepared which call for a 25,000 kilometer path with 12 links. The cumulative effect of the repeated filtering that would be required to prevent adjacent channel interference would result in a channel characteristic like that shown in Figure 3. This type of frequency characteristic reduces intelligibility. Accordingly, in order to maintain high standards of speech quality, it would be necessary to employ channel filters having much sharper attenuation characteristics, thus raising the cost of equipment significantly.

One way of overcoming this problem is to lower the frequency of the out-of-band signaling tone so that it is farther from the edge of the 4-kc band. However, this lowers the highest speech frequency that can be transmitted. Thus, the voice frequency cutoff might be reduced from 3400 to about 3300 cps. This would allow the signaling tone to be reduced from 3825 cps to say, 3700 cycles. Although the top frequency would be lower, this permits the lower cutoff frequency also to be reduced, perhaps from 300 cps to about 200 cycles. This provides a dual ad-

*Consulting Committee for International Telephony and Telegraphy.

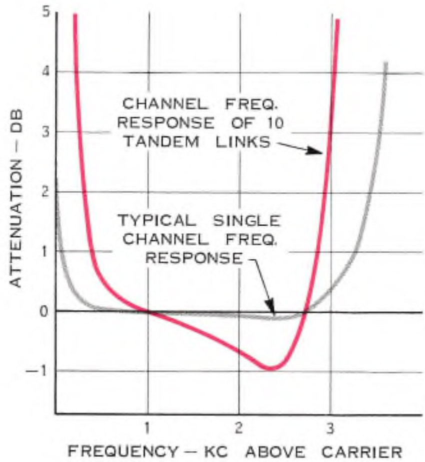


Figure 3. Typical end-to-end channel frequency response is shown by black curve. Variations are retained by each tandem link and tend to become exaggerated as they are repeated. Red curve shows typical degraded frequency response of ten better-than-average channels connected in tandem.

vantage: the image frequency of the signaling tone goes from 175 cps to 300 cycles, well within the effective filter rejection capability. Because of the increased attenuation of the signaling image frequency, supplementary filtering following the demodulator is not required. Actually, quality is improved. Subjective tests by the British Post Office and Bell Laboratories have shown that a frequency band from 200 cps to 3050 cps provides better quality than the band ranging from 300 to 3150 cps, where channel bandwidth must be restricted, as in submarine cables. Studies have shown that voice intelligibility is more dependent on the low frequency end of the voice band than on the high frequency end.

One disadvantage of out-of-band signaling is that it requires some sort of d-c repeater at the end of each link. That is, the signal pulses are detected and made to operate a relay. The relay, in turn, keys the signaling equipment in the succeeding link. Thus, signaling terminals are required at both ends of each link. This has the disadvantage of increasing the cost, complexity, and possible distortion of the signals.

In-Band Signaling

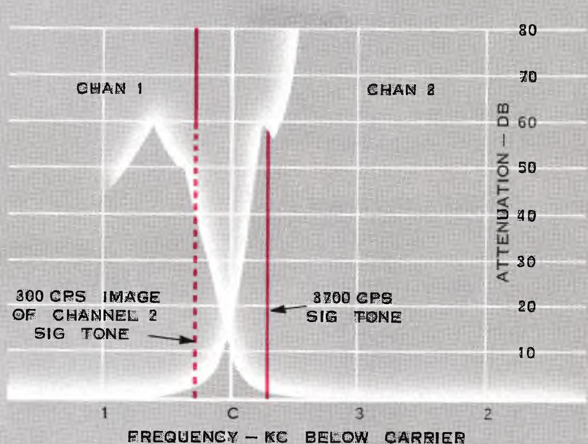
There is a growing trend toward greater use of in-band signaling. This appears to be a natural evolutionary step away from the use of separate channels for signaling. In the earliest days of carrier transmission, all signaling equipment was completely separated from the equipment used for voice transmission. Out-of-band signaling, an intermediate step in this evolution, brought the speech and signaling together in the same communications channel, while keeping a "barrier" between them.

With in-band signaling, the two are even more intimately merged. Signaling tones are transmitted at a frequency within the speech band, usually either 1600, 2400, or 2600 cps. The principal objection to in-band signaling is that the signaling tones lie right in the speech band. This leads to the possibility that speech energy at the signaling frequency may be able to "talk-down" the signaling; that is, cause false signals with voice energy. Conversely, signaling tones are audible and thus cannot be used during conversation.

The biggest advantage of in-band signaling is the extreme flexibility that it provides. The speech and supervisory signals share the same transmission facility, but at different times. The system is arranged so that supervisory signals are on the line only before and after a call. Since the signaling becomes a part of the transmission, it is not necessary to use d-c repeaters when going from one link to another. At branching points, a similar flexibility is obtained. The lack of d-c repeaters eliminates the delay and pulse distortion which characterize out-of-band signals sent through several links.

In-band signaling provides unusual flexibility and economy in large offices.

Figure 4. Greatly improved isolation between adjacent channel speech and signaling results when out-of-band signaling frequency is lowered to 3700 cps, thus shifting image to 300 cycles. Signaling and speech signals are much more effectively attenuated by channel filters.



Since the signals are carried over the speech circuit, it is unnecessary to cable the so-called E & M (receive and transmit) signaling leads through the office. The signaling equipment can be associated directly with the switching equipment, thus allowing a trunk circuit to be obtained from any available transmission medium, rather than being restricted to certain carrier systems.

Preventing Talkdown

In order to prevent spurious signaling by voice energy, a "guard" circuit is commonly used to distinguish between speech and signaling tones. Typically, the guard circuit consists of a network which detects the presence of other frequencies. When other frequencies are present, the guard circuit "assumes" that the signaling tone frequency is caused by speech and therefore prevents signal circuit response.

Further protection can be obtained by proper choice of frequency for the in-band signaling tone. In general, it is desirable to use the highest frequency that can be transmitted easily through

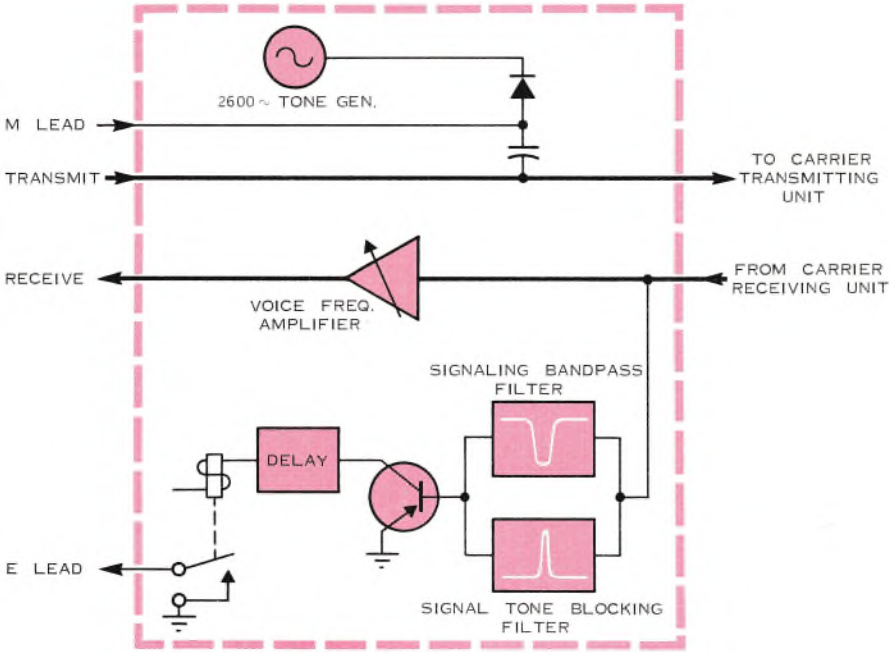


Figure 5. Simplified block diagram of a typical in-band signaling guard circuit designed to prevent "talkdown" or signaling imitation by speech. M lead in transmitting circuit biases diode to cut-off during off-hook condition, keys 2600-cps tone during dialing. At receiver, presence of 2600-cycle tone alone permits transistor to conduct, energizing the signaling relay, and lifting E lead from ground. Presence of other frequencies indicates speech. Energy from the signaling tone elimination filter causes transistor to cut-off, de-energizing the relay and grounding the E lead. Time delay in relay circuit reduces the chance of noise simulating speech and causing improper disconnect.

the worst transmission channel that might be used. Speech energy declines rapidly at the higher frequencies, thus reducing the likelihood of talkdown. Certain older carrier systems have a cutoff frequency near 2800 cycles. For this reason, one of the most commonly used in-band signaling frequencies is 2600 cycles per second. Speech energy at 2600 cps is relatively low.

As a further precaution, a brief time delay on the order of 30 milliseconds reduces the likelihood of speech or noise energy causing spurious signals. Normally, most noise frequencies are very transient. By introducing a delay, the circuit is made relatively insensitive to noise energy at the signaling frequency.

Time Division Signaling

In some new carrier or multiplex systems, a different method of transmitting supervisory signals may be employed. For instance, in Lenkurt's low-cost 81A Exchange Trunk Carrier System, all 24 voice channels share a common signaling channel, with time division providing separation between channels. Each of the signaling leads is connected to a sampling gate. Each channel is sampled in sequence, and the presence or absence of a signaling tone is transmitted to the receiver. In this particular system, signaling is transmitted by shifting the frequency of the level-regulating pilot (which would be transmitted anyway).

At the receiver, the incoming pulses are sorted and distributed to the appropriate channels. Although this arrangement lacks the flexibility of in-band signaling, it does provide unusually reliable and economical signaling without encroaching on the bandwidth available for each channel. By associating most of the signaling functions with the common equipment, cost of the system is substantially reduced without reducing quality or reliability, an important consideration in short-haul systems.

Similarly, time division multiplex systems now appearing commercially transmit PCM code pulses to represent speech information in each channel, then transmit an additional impulse for signaling information, in much the same manner as in the Lenkurt 81A equipment. The method used in the 81A system is the time-division equivalent of separate-channel signaling, while the time division multiplex system is the equivalent of out-of-band signaling. Perhaps this more sophisticated use of combinations of modulation methods for transmitting supervisory signals represents the next major step in the evolution of efficient signaling. •

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