# Near-Far Interference in Digital Wireless Communications

## This article illustrates the problems that arise in narrowband wireless systems due to large signal level variations with changing distance between transmitter and receiver

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Near-far interference is shown to be a potentially serious problem for low cost narrowband digital wireless communications systems. In this article, low hardware cost implementations of both BFSK and BPSK transmitters are evaluated, and the near-far interference performances of these two modulations are compared. Measurements are reported for both modulations showing the onset near-far interference. Path loss is the only transmission effect considered. Two significant results of this analysis are: 1) that unfiltered BPSK is far more prone to cause near-far interference than unfiltered BFSK, and 2) to avoid near-far interference, modulations must be used that constrain the occupied spectrum within a level of –70 dBr to –100 dBr.

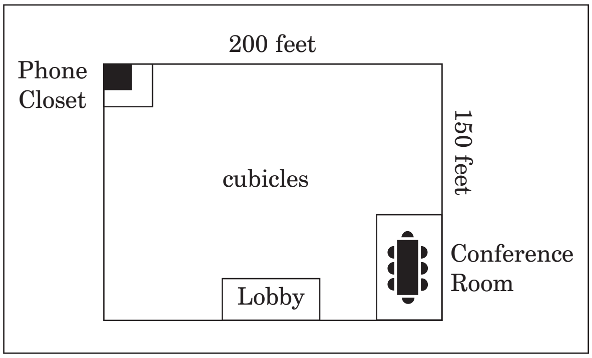
### Introduction

Range is a primary concern in the design and development of wireless (radio) communication products. As such, a great amount of attention is paid to the performance of the radio link at a long distance. As more of these radio products are put into use within the same band, they must inevitably operate in closer proximity to each other. This increases the probability of near-far interference [1].

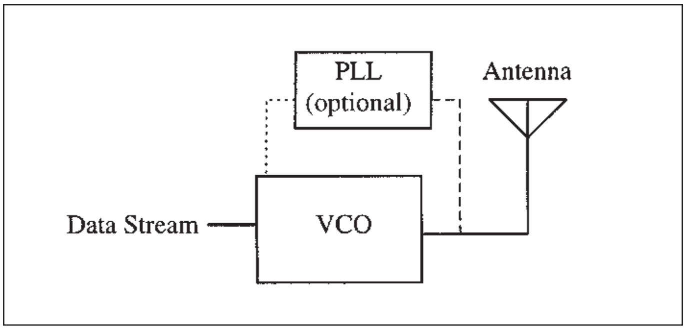
One possible scenario where this situation would arise is the use of wireless PBX (private branch exchange) within a company, as shown in Figure 1. This figure could represent a single floor, or the entire building. The phone closet is in the rear corner. In the opposite front corner is the main conference room, where a number of employees are gathered, say a team of 12. One benefit of wireless PBX is that everyone can carry their phones with them, which we assume that this team has done. At a break in the meeting, everyone pulls out their phones (which had been turned off) to check their messages. There are now 12 radios operating within one meter of each other in the conference room transmitting to the phone closet, and wanting to clearly receive the weak signals from the phone closet. This paper will show that this scenario is likely to be limited by near-far interference.

For this analysis, the simplest and lowest cost radio hardware is considered [2, 3]. All of these transmitters use unfiltered data streams in their modulators. The first are voltage controlled oscillators (VCOs) which are directly modulated by the desired digital data stream. This produces a binary frequency shift keyed (BFSK) signal. The bandwidth of this BFSK signal is examined with respect to Carson's rule, and then the near-far interference characteristics of this signal are examined. Figure 2a shows the model system. It is noted that the VCO may be stabilized with a phaselock loop (PLL) to set and hold the carrier frequency. This does not affect the reported results.

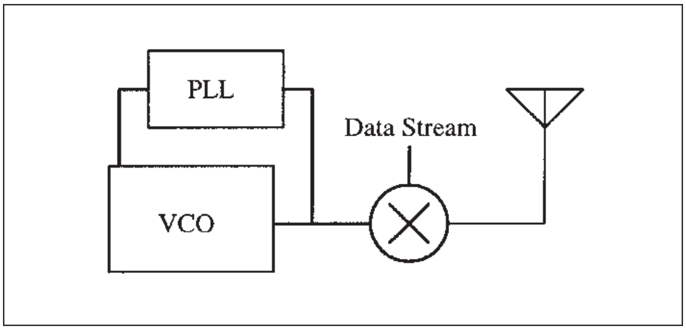
Another simple transmitter structure uses a mixer or other multiplier to invert the phase of the RF source in accordance to the data stream. This produces a binary phase shift keyed




■ **Figure 1. Building layout for the test scenario.**




■ **Figure 2a. Simple BFSK transmitter model.**




■ **Figure 2b. Simple BPSK transmitter model.**

(BPSK) signal, and is shown in Figure 2b. It is recognized that this is also a double sideband suppressed carrier amplitude modulator (DSB-AM-SC), therefore, this BPSK signal is a linear modulation.

## Narrowband radio link parameters:
## A. System model description

For this paper, narrowband communications are defined to be the use of data rates under 100 kilobits per second (kbps). Common data rates in this range include 48 kbps and 9.6 kbps. This paper uses 50 kbps as the data rate ($f_b$) in all calculations and experiments. For the BFSK signal, we also include the restriction that the modulation index be less than unity. For these measurements we choose the modulation index ($h$) to be 0.8, and then the signal deviation ($\Delta f$) is found from

$$\Delta f = f_b \times h = 40 \text{ kHz}_{\text{p-p}} \qquad (1)$$

With the modulation rate and deviation set, the signal bandwidth can be estimated by using Carson's rule [4]. The BFSK estimated signal bandwidth is

$$BW_{est} = 2(h+1)f_m = 2(20+25) = 90\,\text{kHz} \qquad (2)$$

where $f_m = f_b/2$. Figure 3 shows that this estimate of the signal bandwidth is wider than the mainlobe by a factor of 90/60 = 1.5.

The BPSK signal has no independent bandwidth parameter. The BPSK output spectrum, being the result of a linear modulation, is the double-sided translation of the baseband spectrum of the applied data stream. For random data modeled with a pseudo-random bit stream (PRBS) the baseband has the shape of $\sin(x)/x$, with nulls at the data rate and its harmonics. Figure 4 shows the BPSK output spectrum under the same measurement conditions as Figure 3. The linearity of the BPSK modulation is clearly evident. It is also particularly interesting to note the notch in the center of the BPSK spectrum, which shows that the carrier is indeed suppressed.

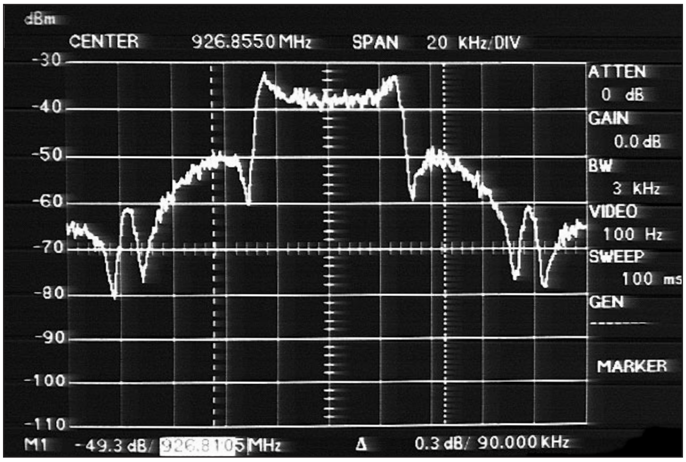
## B. Near-far analysis path loss model

Let $P_t$ be the transmitter power. Then at a distance d from the transmitter the radiated power density $W(d)$ is

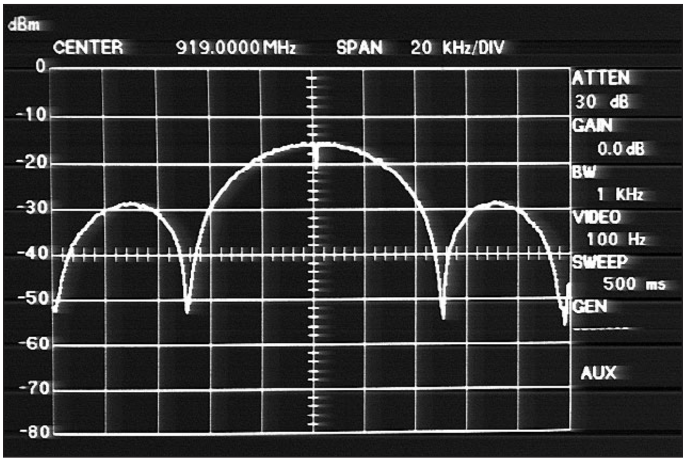
$$W(d) = \frac{P_t}{4\pi d^2} \qquad (3)$$

for an isotropic antenna with unity gain. For directional antennas this is generalized to

$$W(d) = \frac{P_t G_t}{4\pi d^2} \qquad (4)$$




■ **Figure 3. Spectrum of the BFSK test signal with markers showing the bandwidth predicted by Carson's Rule.**




■ **Figure 4. Spectrum of the BPSK test signal showing the width of the main lobe is 100 kHz, twice the data rate.**

where $G_t$ is the antenna gain in the direction of interest. The receiving antenna picks up the signal by intercepting this power density with an effective area of

$$A_{eff} = \frac{\lambda^2 \times G_r}{4\pi} \tag{5}$$

which yields the total received power as the product $W(d)A_{eff}$

$$P_r = \left(\frac{\lambda}{4\pi d}\right)^2 P_t G_t G_r = P_t G_t G_r \left(\frac{\lambda}{4\pi}\right)^2 \frac{1}{d^2} \tag{6}$$

assuming free space propagation. This is the traditional one-over-r-squared propagation model. We define the propagation constant ($p$) for this model to be the exponent of the distance term $d$: $p = 2$.

Experience has shown that radio propagation indoors has higher loss than this predicts. A more realistic model considers that the propagation constant may be higher than 2 so that

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi}\right)^2 \frac{1}{d^p} \qquad p \geq 2 \tag{7}$$

Even more realistic models take into account that the propagation constant may change between the transmitter and receiver. One form of this model [6] is converted to provide received signal power as

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \left(\frac{d_0}{d}\right)^p \qquad d > d_0 \tag{8}$$

but this model is only valid beyond the breakpoint distance $d_0$. The most useful propagation model for doing near-far analyses takes N breakpoints and their associated following propagation constants into account in the single equation

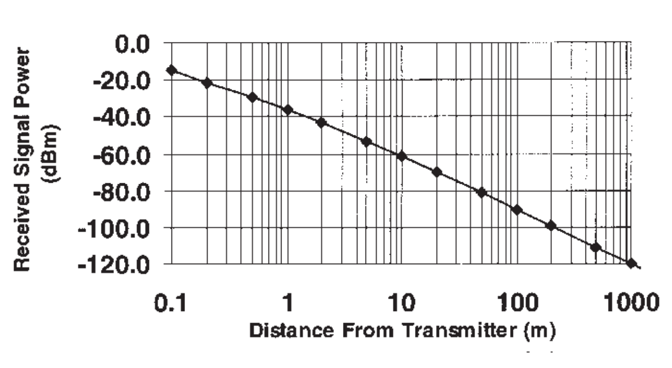
$$P_r = \frac{P_t G_t G_r}{d^{P_0}} \left(\frac{\lambda}{4\pi}\right)^2 \times \prod_{i=1}^{N} \frac{1}{\left(1 = \frac{d}{d_i}\right)^{P_i - P_{i-1}}} \tag{9}$$

For this analysis, we examine the environment of an individual phone in the conference room. From the phone closet, assume that the propagation is free-space within the 10-foot 'closet', so that $p_0 = 2$. Through the intervening cubicles and into the conference room, assume the propagation constant is 3. This yields a model with a single breakpoint, and (9) becomes:

$$P_r = \frac{P_t G_t G_r}{d_2} \left(\frac{\lambda}{4\pi}\right)^2 \times \frac{1}{\left(1 + \frac{d}{3}\right)^{3-2}} \tag{10}$$

| | | |
|---|---|---|
| $N_0$ | –174 dBm/Hz | thermal noise floor power density |
| NBW | 50 dB Hz | = 10 log(100 kHz), noise bandwidth |
| NF | 10 dB | overall receiver noise figure |
| SNRd | 13 dB | design predetection signal-to-noise ratio |

■ **Table 1. Receiver sensitivity parameters.**




■ **Figure 5. Received signal power vs. distance from the transmitter for the test scenario.**

## Range calculations

To evaluate (10) so we can perform range calculations it is necessary to know the transmitter power and frequency. In the USA much of the low cost wireless product activity is in the unlicensed UHF spectrum allocations as defined in Part 15 of the FCC Regulations [7]. In particular, section 249 of Part 15 is most appropriate to minimum cost radios. This part limits the radiated field strength (E) to 50 millivolts per meter at a distance ($d_m$) of 3 meters, at a minimum nominal frequency of 915 MHz. Assuming a unity gain isotropic antenna, this regulation corresponds to a transmitter power of [8]

$$P_1 = \frac{4\pi d_m^2 E^2}{\eta_0} = \frac{4\pi \times 3^2 \times 0.05^2}{377} = 0.75\,\text{mW} \tag{11}$$

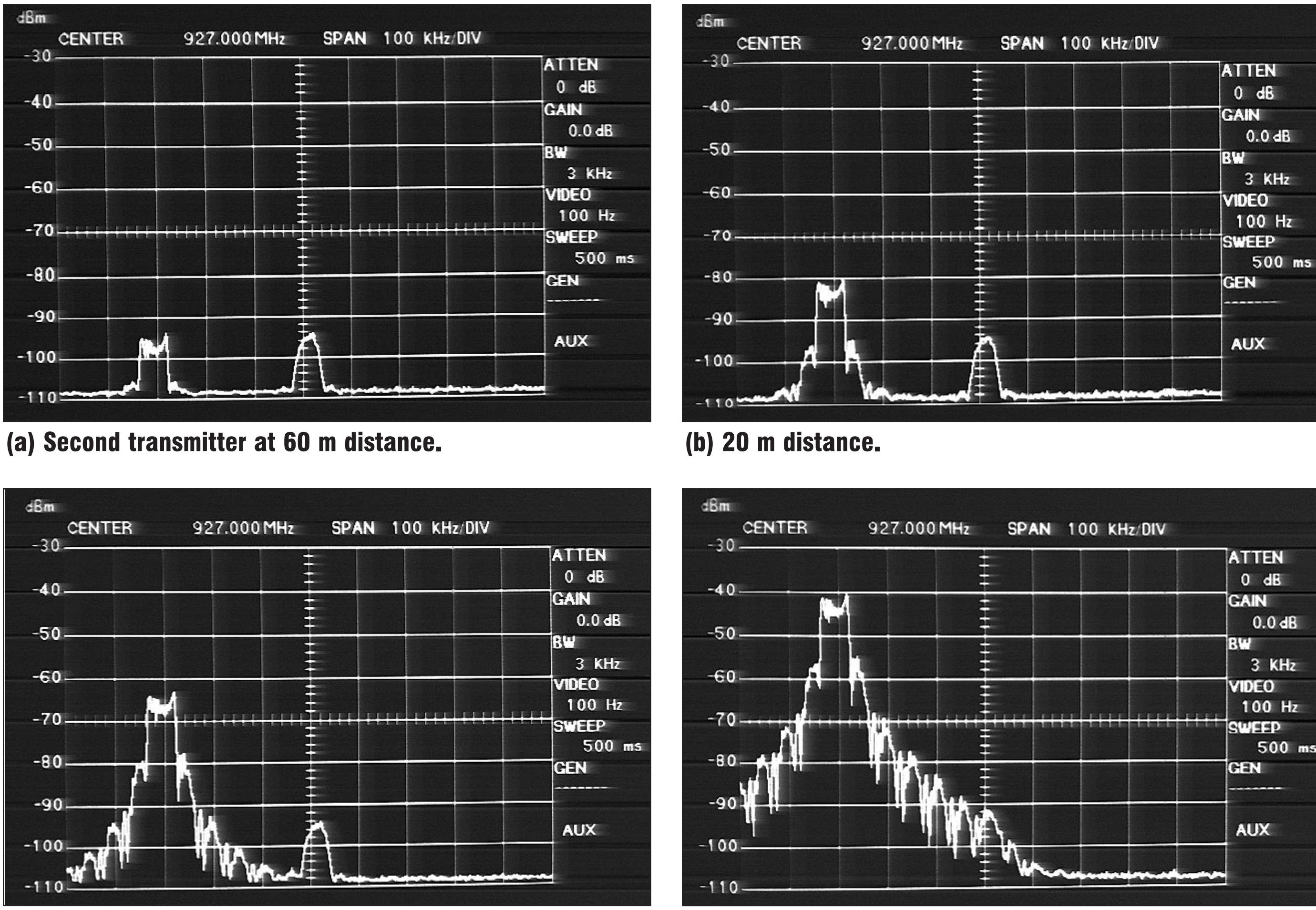
where

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$$

is the intrinsic impedance of free space, which is 377 Ω [5].

In a 50Ω system this corresponds to a power level of –1.2 dBm. This provides the missing information needed to evaluate (10). Setting $P_t = 0.75$ mW, and $G_t = G_r = 1$, the received signal strength vs. distance is calculated and shown in Figure 5. Note the change in slope around $d = 3$m.

The next step is to determine the minimum acceptable receiver power necessary for communication. This




**(a) Second transmitter at 60 m distance.** **(b) 20 m distance.**

**(c) 5 m distance.** **(d) 0.5 m distance.**

■ **Figure 6. Near-far interference develops as a BFSK transmitter draws closer to a receiver. For all measurements the transmitter of the desired signal is 60 m. away. The second transmitter is measured at varying distances.**

is defined as the sensitivity S, which is initially estimated by the decibel equation

$$S = N_0 + NBW + NF + SNRd \quad (12)$$

Table 1 contains the parameters used in the evaluation of S. They are not nearly state-of-the-art, but are quite conservative to be representative of a very low cost radio. The bandwidth of the system is taken to be 100 kHz, which is just above the bandwidth predicted by Carson's Rule for this signal. Substituting all of this into (12), the sensitivity is found to be

$$S = -174 + 50 + 10 + 13 = -101 \text{ dBm} \quad (13)$$

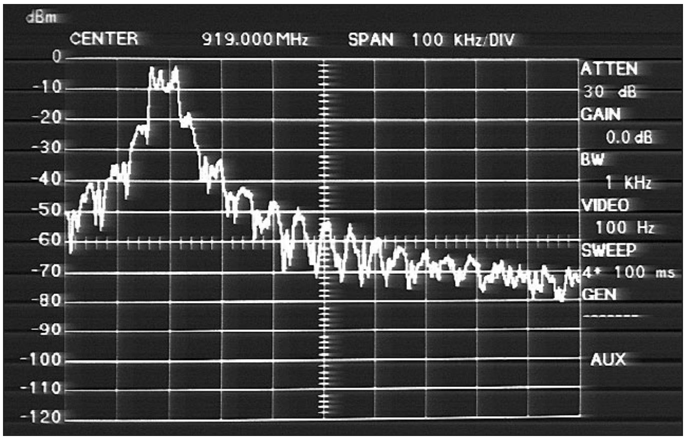
Range is now estimated by combining the propagation model with the receiver sensitivity. Reviewing Figure 4, we see that the propagation model crosses the –100 dBm receiver input power level at a distance of 200 m, or about 650 ft. From the application described in Figure 1, this system has sufficient range by nearly a factor of three.

## Near-far interference measurements

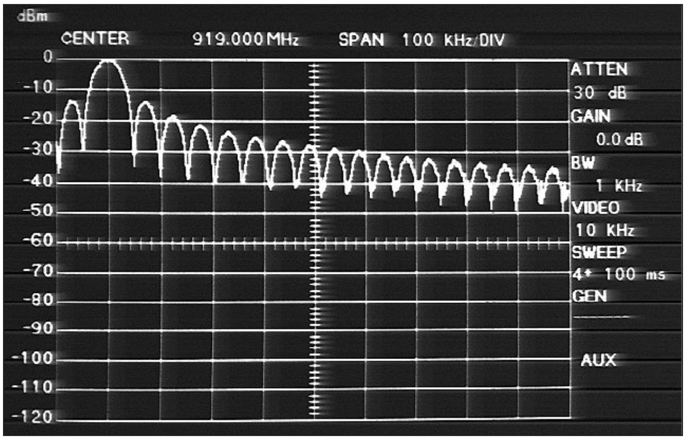
The system model developed above shows that at a 250 foot range indoors, the expected received signal power is nominally –85 dBm (from Figure 5). This is 15 dB above the receiver's sensitivity, so communication is expected to be robust. But from another radio operating at 0.5 m distance, the received signal power is –30 dBm. This is 55 dB higher than the desired receiver input signal. Selectivity filters in your radio are designed to reject this large signal at a different frequency. However, a problem still arises if the sidebands of the nearby transmitter are sufficiently strong at your operating frequency. Then the near transmitter provides sufficient signal to interfere with the reception of the desired weak signal from the far transmitter. This is known as near-far interference.

## BFSK signals

Let the interfering transmitter be three 100 kHz channels away. The photographs in Figure 6 show the radio environment seen by one phone in the conference room with only one other phone operating. The weak



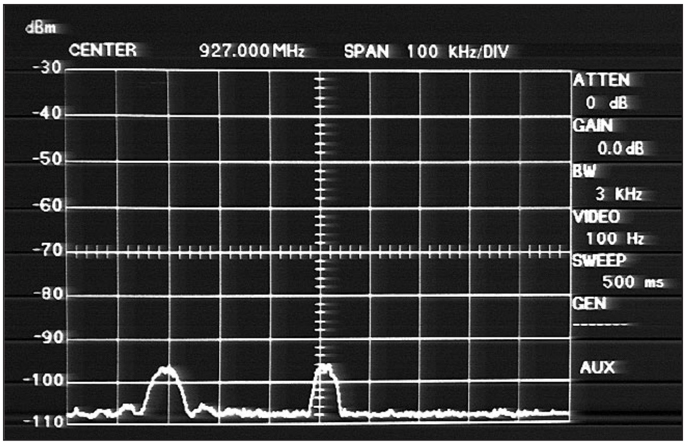

■ **Figure 7a. Wideband measurement of sidebands from the simple transmitter: BFSK.**



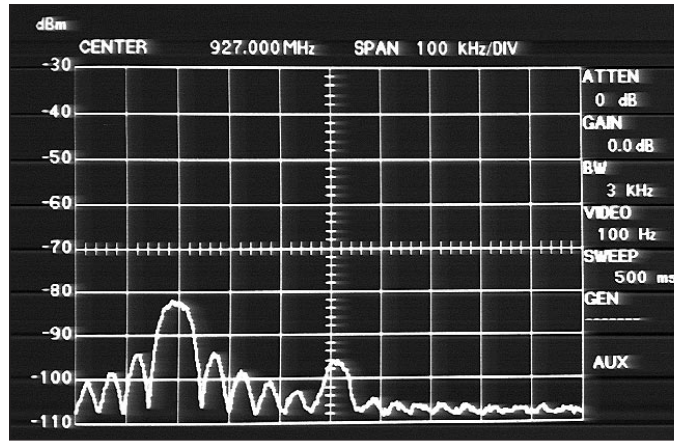

■ **Figure 7b. Wideband measurement of sidebands from the simple transmitter: BPSK.**

signal in the center of each photograph is the signal arriving to you from the phone closet. The signal at 300 kHz lower frequency is the other phone's transmitter, operating at different distances from your phone. It is no surprise that as the other phone gets closer, its signal gets stronger. It must be remembered that the received signal powers predicted by (10) and shown in Figure 5 are total signal powers, including all modulation sidebands. The power spectral densities of the photographs all have these total powers, even though the center of the modulated spectral density measures lower.

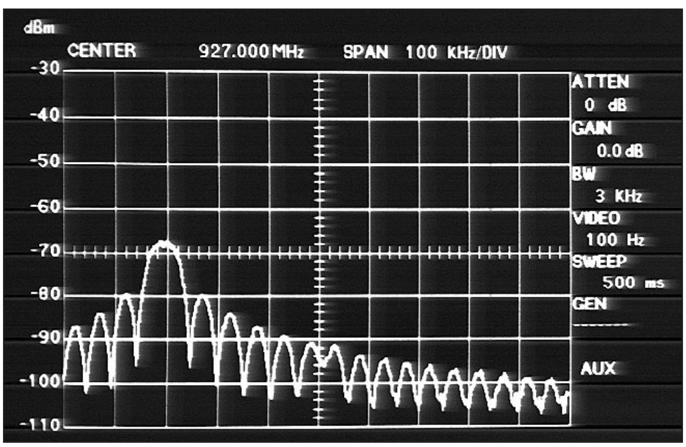
But when the other phone is very near, its sidebands have essentially overrun the desired signal. With overlapping energy present at the same frequency, filtering can no longer separate these two signals. The nearby transmitter has successfully interfered with the reception of the weaker signal, and communication on the original channel is lost. To regain communications, the



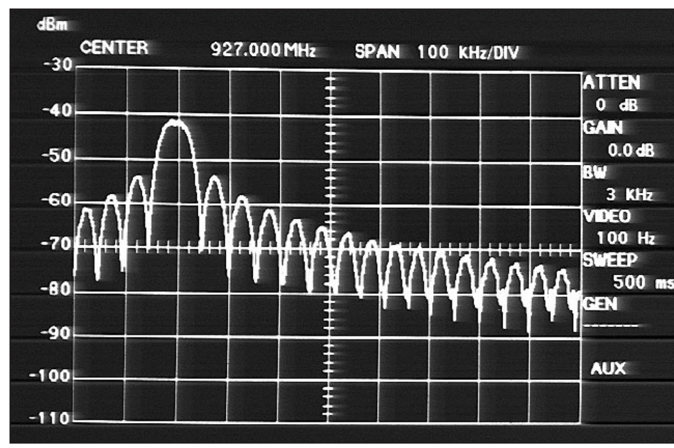

**(a) Second transmitter at 60 m distance.**




**(b) 20 m distance.**




**(c) 5 m distance.**




**(d) 0.5 m distance.**

■ **Figure 8. Near-far interference develops as a BPSK transmitter draws closer to a receiver. For all measurements the transmitter of the desired signal is 60 m away. The second transmitter is measured at varying distances as shown.**

transmitter sidebands will need to be constrained so they are at least –70 dBc at the 300 kHz test offset frequency.

This onset of near-far interference occurs even with transmitter power below one milliwatt. Other available and pending regulations allow transmitter powers between 100 times and 1000 times higher. In these cases, the onset of near-far interference is much sooner, in other words, the nearby interfering transmitter does not have to be as ‘near.’ A wideband measurement of the sidebands from this simple modulated VCO transmitter is shown in Figure 7a. This measurement shows that the transmitter sidebands are 70 dB down at 800 kHz offset from the transmit carrier. These sidebands are dropping in magnitude at 12 dB per octave offset. This is seen from Figure 7a by taking the offset frequency pairs 100 and 200 kHz, 200 and 400 kHz, 300 and 600 kHz, and 400 and 800 kHz. A slope of 12 dB per octave is identical to 40 dB per decade, an equivalent of a 2-pole rolloff. If this transmitter were allowed to operate 1000 times stronger than that of Figure 6, then its sidebands would be 10 log(1000) = 30 dB higher at the same distances. Near-far interference would begin at a distance between 10 and 20 meters. To regain full operation at the close distances of the group in the conference room, the transmitter sidebands must be constrained to levels of –80 dBc to –100 dBc for these higher output powers.

## BPSK signals

Near-far interference is not limited to systems of the same type of radios. Figure 8 shows the effect of changing distances between a simple BPSK transmitter and the same BFSK link operating at 60 m range as before. The BPSK transmitter has the same output power as the BFSK transmitters, and operates under the same FCC regulation, 15.249. The onset of near-far interference is evident at a distance of 20 m, which is far sooner than that seen with the BFSK system. Figure 8c shows that by the time the BPSK transmitter is within 5 m of the BFSK receiver, the BFSK link is completely interfered with and its communication is lost. At the very close spacing of Figure 8d the presence of the BFSK signal is completely undetectable.

The wideband measurement of the sidebands from this simple BPSK transmitter is shown in Figure 7b. This measurement shows that the transmitter sidebands are 35 dB down at 800 kHz offset from the transmit carrier. These sidebands are dropping in magnitude at 6 dB per octave offset, a dB slope that is exactly one half that of the BFSK transmitter. A slope of 6 dB per octave is identical to 20 dB per decade, an equivalent of a 1-pole rolloff. As discussed for the BFSK transmitter, if the BPSK transmitter were allowed to operate 1000 times stronger than that of Figure 8, then near-far interference would be in full effect at 60 m. Thus, a higher power simple BPSK transmitter is likely to render the building-wide wireless PBX system inoperative. To attain full operation at the close distances of the group in the conference room, the transmitter sidebands still must be constrained to levels of –80 dBc to –100 dBc for these higher output powers.

In any application where the use of these simple transmitters is mandated for cost reasons, if the distribution of transmitters and receivers is such that one transmitter is much closer than the others, then the choice of modulation has a large impact on the possibility of system impairment due to near-far interference. The linear modulation of the simple BPSK transmitter produces sidelobes that fall off much more slowly than those of the BFSK transmitter. This energy is much more likely to interfere with other communications in the same band. The use of unfiltered simple BPSK transmitters is not a 'good-neighbor' policy in the unlicensed general use bands.

## Conclusion

Near-far interference is a serious potential problem for narrowband digital wireless communications systems. This is especially true for the lowest cost hardware architectures. These measurements demonstrate that BFSK and BPSK modulations behave very differently with respect to near-far interference. Measurements of the BFSK directly modulated VCO show that sidebands of significant magnitude exist at significant frequency offsets from the carrier. Yet, these BFSK sidebands are suppressed twice as much (in dB) as those of the simple BPSK transmitter. These sidebands represent energy that can interfere with other desired signals. The use of the simple BPSK transmitter is the worst case for causing near-far interference.

Near-far interference could effect a significant reduction on the communication capacity of a radio band. Spectrum space that is occupied by sidebands is not necessarily available for use by other communicators, especially if they are closely spaced. In order to get the maximum communication capacity out of these narrowband digital communications systems, it is necessary to constrain the signal sidebands to at least –70 dBr. If higher transmitter powers are used, the level that the spectrum must be constrained within moves to –80 dBr and could go as far as –100 dBr. This is a coming challenge for radio hardware designers. ■

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