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Feasibility of Using Frequency Offset on Very High Frequency Air/Ground Voice Channels

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March 1990

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16. Abstract

In some large Federal Aviation Administration (FAA) air traffic control sectors, the controller manually switches between multiple ground transmitters to communicate with aircraft at opposite ends of the sector. This puts an additional burden on the controller.

Aeronautical Radio, Inc. (ARINC) uses a frequency offset system which produces five frequencies from one channel assignment. ARINC provides this service to commercial air carriers who use receivers designed to ARINC specifications. These receivers are capable of eliminating the audio heterodyne generated by the offsetting process. The commercial air carriers use this system for airline business.

This report describes the testing performed at the FAA Technical Center to evaluate this system as a means of controlling air traffic in large sectors.

The tests indicate that a frequency offset system cannot be used with general aviation aircraft receivers because many cannot filter out the audio heterodyne. Use of frequency offset may be possible in high altitude sectors where commercial aviation receivers, which meet ARINC specifications, are used if some additional concerns are resolved.

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BACKGROUND

In some large Federal Aviation Administration (FAA) air traffic control (ATC) sectors, the controller must manually switch between multiple transmitters/ receivers to provide coverage at opposite ends of the sector. While this provides satisfactory communications throughout the sector, it places an additional burden on the controller and a solution is desired. Since the aviation very high frequency (VHF) communications band (118 to 136 megahertz (MHz)), which is capable of providing 720 channels, is already facing a critical shortage of frequencies, providing an additional frequency is not always possible.

Aeronautical Radio, Inc. (ARINC), which provides services in this band to commercial aircraft, uses a single channel cross-country by offsetting the ground transmitter frequencies. By using the channel frequency and four offsets, five "channels" are produced from one frequency assignment. Aircraft traveling cross-country tune to the channel frequency and can receive it and the offsets without retuning. To prevent the annoying audio heterodyne generated by adjacent offsets, additional audio filtering is incorporated into the receiver design. Air carrier receivers using this system must meet either ARINC Technical Specification 566 or 716, "Airborne VHF Communications Transceiver" which includes tight specifications on filtering and stability to allow for this type of offset operation.

Consideration of this frequency offset technique for possible use by the FAA for air/ground communication frequencies is the subject of this report. A key consideration for using this technique is whether non-ARINC specification general aviation receivers could provide adequate performance without an additional filter. At the request of the Spectrum Engineering Division, ASM-500, the FAA Technical Center conducted tests to examine the feasibility of using frequency offset. The receivers tested in this study were all produced under FAA Technical Standard Order (TSO) C38b.

TEST PROCEDURE

Using two signal generators equally spaced, 5 kilohertz (kHz) above and below 127.375 MHz, the ARINC frequency offset system was simulated on the bench. Both signal generators were adjusted to provide equal signal levels of -87 decibels above 1 milliwatt (dBm) at the receiver input. This level was selected to represent the minimum level expected in the service volume. Equal signal levels were used because preliminary testing indicated this condition generated the largest heterodyne.

Tests were conducted on one air carrier receiver (receiver 1) and two general aviation receivers (receivers 2 and 3) tuned for 127.375 MHz. Previous FAA Technical Center testing showed general aviation receiver 2's performance to be comparable to air carrier receivers. Tests were performed using (1) no modulation, (2) a 1000-hertz (Hz) tone at 90-percent modulation, (3) a 1000-Hz tone at 30-percent modulation, (4) voice at 90-percent modulation, and (5) voice at 30-percent modulation. The 30-percent modulation was used because it is a standard test level used by receiver manufacturers. The 90-percent modulation is the level FAA ground transmitters are adjusted to. Voice was a tape recording of 20 ATC phrases. Conditions 1 and 2 were also produced using two FAA ground transmitters

(AN/GRT-21), offset +/- 5 kHz, to confirm that the signal generators could accurately simulate the desired test conditions. The transmitters were connected to two antennas and radiated to a receive antenna over 100 feet away. The transmitter outputs were attenuated to produce -87 dBm at the receiver input. The signal generators were connected to the receivers via cable. The test setups are shown in figures 1 and 2 and a tabulation of the test conditions is listed in table 1. The voice modulation tests were also conducted with 3 and 4 kHz offsets.

To reduce the effect of the heterodyne, it is necessary to select offsets which place the heterodyne outside the avionic transceiver's 300- to 2500-Hz audio passband. Conversely, it is also desirable to keep the audio response within the transceiver's 6 decibel (dB) intermediate frequency (IF) bandwidth (typically 8 kHz). These limiting and opposing factors make frequency offsets of +/- 3, 4, and 5 kHz good choices for this study.

All data were recorded at the audio output of the receiver with a spectrum analyzer. Audio tape recordings were also made of the voice tests.

TEST RESULTS AND ANALYSIS

The data will be presented in groups of three with each group showing the three receiver responses to the same test conditions.

CARRIERS ONLY.

Figures 3 through 8 show the receiver's audio output when exposed to two unmodulated carriers offset +/- 5 kHz from the channel frequency. The first three figures show receiver response when the signal generators are used as the transmit source and the next three figures are with the transmitters as the transmit source. It is seen that each receiver's response to either the signal generator or the transmitter is virtually the same with the exception of a slight shift in heterodyne frequency which is due to normal tuning differences between the signal generators and transmitters. The signal at approximately 20 kHz is the second harmonic of the heterodyne. The 11.4 kHz signal on figures 4 and 7 is part of the heterodyne. Any heterodynes above 20 kHz are not plotted because they are above the range of human hearing. Receivers 1 and 2 generated a heterodyne that was over 40 dB above the surrounding noise floor and about equal to the inband (300 to 2700 Hz) noise level. This produced a 10-kHz tone that was just audible. It is seen that the performance of receiver 2 (general aviation) is similar to that of the air carrier receiver. This information is also presented in table 2. Receiver 3 had a heterodyne 42 dB above the surrounding noise floor but also 22 dB above the in-band level. This heterodyne was far more noticeable to this observer. It is important to remember that although the heterodyne occurs outside the audio passband of the receiver, it is still within the range of human hearing.

TABLE 1. TEST CONDITIONS

Figure Numbers	Modulation Type	Offset +/- kHz	Signal Source
3-5	None	5	SG
6-8	None	5	TX
9-11	90% Tone	5	SG
12-14	90% Tone	5	TX
15-17	30% Tone	5	SG
18-20	90% Voice	3	SG
21-23	30% Voice	3	SG
24-26	90% Voice	4	SG
27-29	30% Voice	4	SG
30-32	90% Voice	5	SG
33-35	30% Voice	5	SG

TX = Transmitter SG = Signal Generator

Signal Level = -87 dBm. Tone is 1000 Hz.

TABLE 2. HETERODYNE LEVEL WITH RESPECT TO OTHER RECEIVER SIGNAL LEVELS

	Receiver Number		
	1	2	3
No Modulation +/- 5 kHz	46 / 0 / --	42 / 0 / --	42 / 22 / --
90% Tone +/- 5 kHz	46 / 10 /-42	40 / 2 / -39	38 / 14 / -26
30% Tone +/- 5 kHz	44 / 2 / -39	43 / 1 / -37	43 / 19 / -10
90% Voice +/- 3 kHz	42 /-4 / -36	42 / 3 / -26	37 / 14 / -4
30% Voice +/- 3 kHz	42 /-5 / -34	42 / 6 / -6	37 / 14 / 1
90% Voice +/- 4 kHz	44 /-3 / -38	40 / 2 / -33	42 / 22 / 0
30% Voice +/- 4 kHz	44 /-2 / -28	42 / 4 / -10	42 / 22 / 3
90% Voice +/- 5 kHz	47 / 2 / -30	39 / 0 / -28	42 /20 / 0
30% Voice +/- 5 kHz	46 / 0 / -18	39 / 0 / -27	42 / 20 / 2

Data is in dB with respect to the following reference points:

Above out-of-band noise floor / Reference to in-band noise floor / reference to modulation peak.

A negative number indicates heterodyne is below reference point.

TONE MODULATED.

Figures 9 to 17 plot tests that were conducted with +/- 5 kHz offsets modulated either 30 or 90 percent by a 1000-Hz tone. Figures 9 to 11 are with the signal generators modulated 90 percent; figures 12 to 14 are with the transmitters modulated 90 percent; and figures 15 to 17 are with the signal generator modulated 30 percent. All receivers responded the same whether the signal generators or the transmitters were used. The additional signal peaks are sidebands of the heterodyne which were formed by the mixing of the two channels. On receivers 1 and 2 and at both modulation levels, the heterodyne was just barely audible and gave a very slight warble to the 1000-Hz tone. With 90-percent modulation, the heterodyne is about 40 dB below the 1000-Hz tone. At 30 percent, it is at least 37 dB down. Again, receiver 2's performance (general aviation) is similar to the air carrier receiver. Receiver 3's heterodyne was far more noticeable at both modulation levels. At 90-percent modulation, it was 26 dB below the 1000-Hz tone but at 30 percent, it was only 10 dB down. On all receivers, the heterodyne is above the in-band noise level.

VOICE MODULATION.

Since the above test showed that the receivers' response was the same for the signal generators or transmitters, the voice tests were performed using only the signal generators. Tests were conducted with 3, 4, and 5 kHz offsets with both 90- and 30-percent modulations. Receiver voice response with +/- 3 kHz offset is shown in figures 18 to 23 with the first three figures showing 90-percent modulation and the next three figures showing 30 percent. At both modulations, receiver 1's heterodyne is 42 dB above the noise floor and about 35 dB below the voice peaks. On the 90-percent plot, the voice sidebands of the heterodyne are seen above 2700 Hz. Receiver 2's heterodyne was 42 dB above the noise floor for both modulations and 26 dB below the voice peaks at 90-percent modulation. At 30 percent, it is only 6 dB below the voice. At both modulations, receiver 3 produced a heterodyne 37 dB above the noise floor. At 90 percent, it is only 4 dB below the voice peaks and at 30 percent, it is 1 dB above the voice peaks.

The response at +/- 4 kHz is shown in figures 24 to 29 and the +/- 5 kHz response is shown in figures 30 to 35. The response was similar to the +/- 3 kHz response discussed above. Table 2 tabulates the data.

For all offsets, receivers 1 and 2 produced a heterodyne that was just noticeable in the background. The heterodyne generated by receiver 3 produced a predominate tone that was overwhelming even during voice reception.

DISCUSSION

RECEIVERS.

Three receivers were used for this project. They are listed below in no particular order and the letters do not correspond to receivers 1 through 3 referenced throughout the report.

A. King KY-92
B. King KY-197
C. Collins 618M-3

ARINC SYSTEM.

FAA met with ARINC personnel to discuss their experiences in implementing this system and the feasibility of FAA using a similar system without additional filters. The following paragraphs are based on this discussion.

ARINC generates five channels from one frequency assignment by using the on-channel frequency, +/- 4 kHz, and +/- 8 kHz offsets. Using this system, they provide air-to-ground communications throughout the Continental United States with only 13 frequency assignments.

Many avionics receivers use multiple squelch circuits, one of which is a noise squelch which operates when the signal-plus-noise-to-noise ratio is less than 6 dB. When many ground transmitters are keyed-up and the aircraft is in an area where it is receiving the on-channel frequency and the +/- 8 kHz offset at approximately the same level, some avionics receivers will interpret the offset frequency as a noise level which is equal to the on-channel signal. The receiver squelch will not open under these conditions. This creates dead spots where the aircraft is able to transmit but unable to receive. The ARINC system is used for airline business and the dead spots do not impose a significant impact on their operation. In FAA ATC, where safety of flight is an issue, dead spots are unacceptable. ARINC has experienced this problem with the +/- 8 kHz offset. This is probably less likely with other offsets but should not be ignored.

The ARINC ground transmitters are designed with a frequency stability of 100 Hz (.00008 percent). They have found this stringent stability requirement necessary to prevent the 4 kHz heterodyne, produced by the on-channel and +/- 4 kHz transmitters, from drifting into the audio band. For example, if both transmitters drift 100 Hz closer, the heterodyne will be at 3800 Hz. The air carrier receiver's filters are designed to be at least 20 dB and preferably 40 dB down at 3750 Hz so any further drift would place the heterodyne within the filter's passband. FAA transmitters, with improved crystals installed, have frequency stabilities of 600 Hz (.0005 percent) and if they both drift 600 Hz closer, the heterodyne would occur at 2800 Hz which is well within the filter's passband. This appears to be a problem only if the on-channel frequency is used.

Air carrier receivers incorporate additional audio filters in their design which is needed to eliminate the audio heterodyne. ARINC has found that without filtering, the heterodyne is too annoying for the system to be usable. Many general aviation receivers (even if TSO'd) do not have the necessary filtering.

The ARINC ground receiver's audio outputs are all connected together. This may cause some muffling of the speech but it is still intelligible according to ARINC personnel. ARINC has found that the improvement in speech quality derived from a receiver voting system did not outweigh the reduction in reliability caused by the voting system.

If 12.5-kHz channel spacing is implemented, ARINC will lose the +/- 8 kHz offset frequency but they believe the +/- 4-kHz offset will still be usable.

CONCLUSIONS

Based On Bench Data:

1. Frequency offset produced an audible tone on all three receivers. The tone produced by the heterodyne in receiver 3 was particularly objectionable. The tone generated in receivers 1 and 2 were just audible in the background.

2. Using a frequency offset system without additional avionics audio filters is not feasible due to the large heterodyne generated in some avionics transceivers.

Based On Discussion With Aeronautical Radio, Inc. Personnel:

1. Aeronautical Radio, Inc. (ARINC) indicated the following areas need to be considered even when appropriate ARINC transceivers are used:

a. The noise squelch induced dead spot issue must be resolved.

b. Operation beyond the 6 decibel (dB) intermediate frequency (IF) bandwidth must be acceptable for air traffic control (ATC).

c. Improved crystals need to be installed in the ground transmitters and the on-channel frequency cannot be used.

d. The ground receiver audio muffling must be acceptable to ATC personnel.

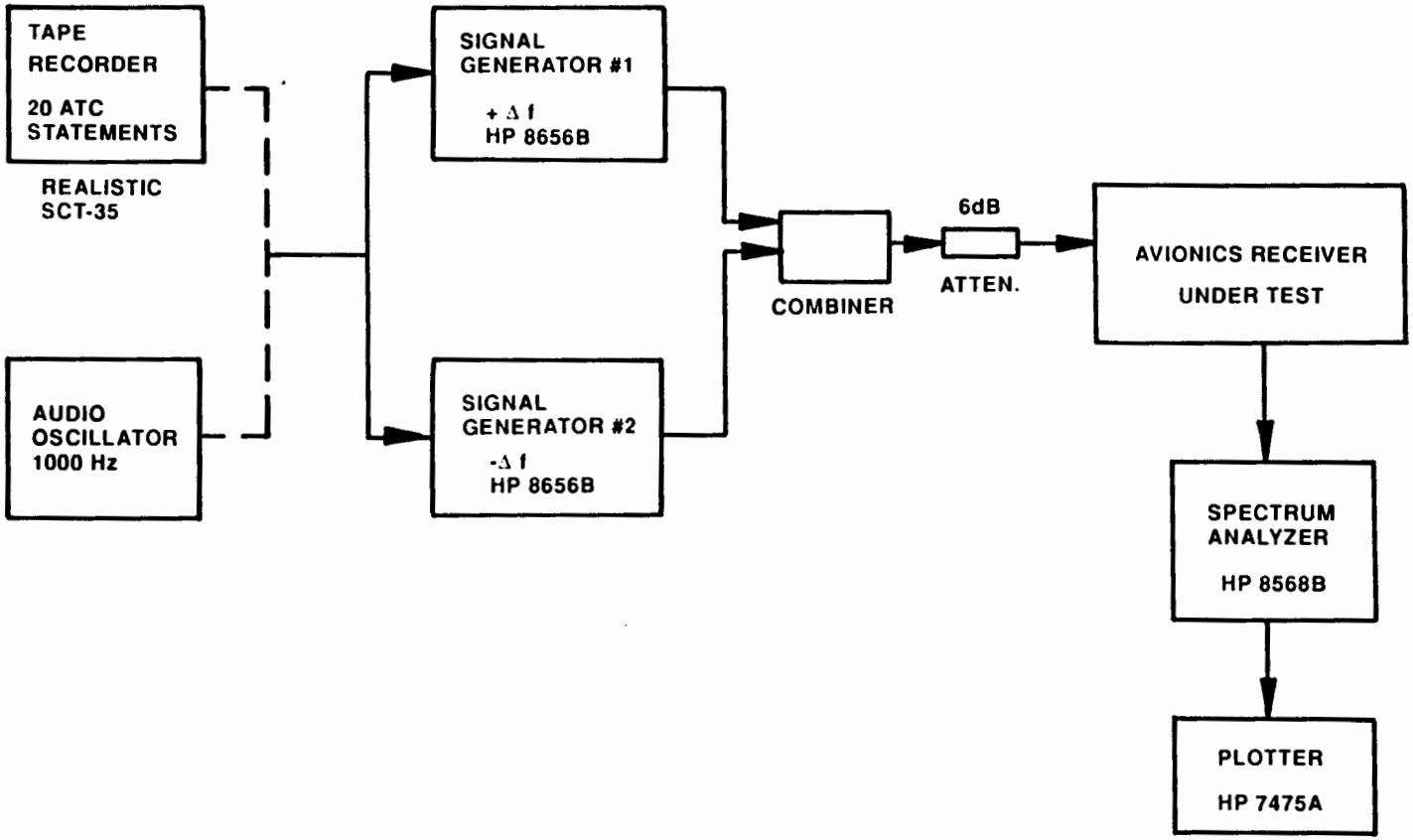

FIGURE 1. TEST SETUP USING SIGNAL GENERATORS

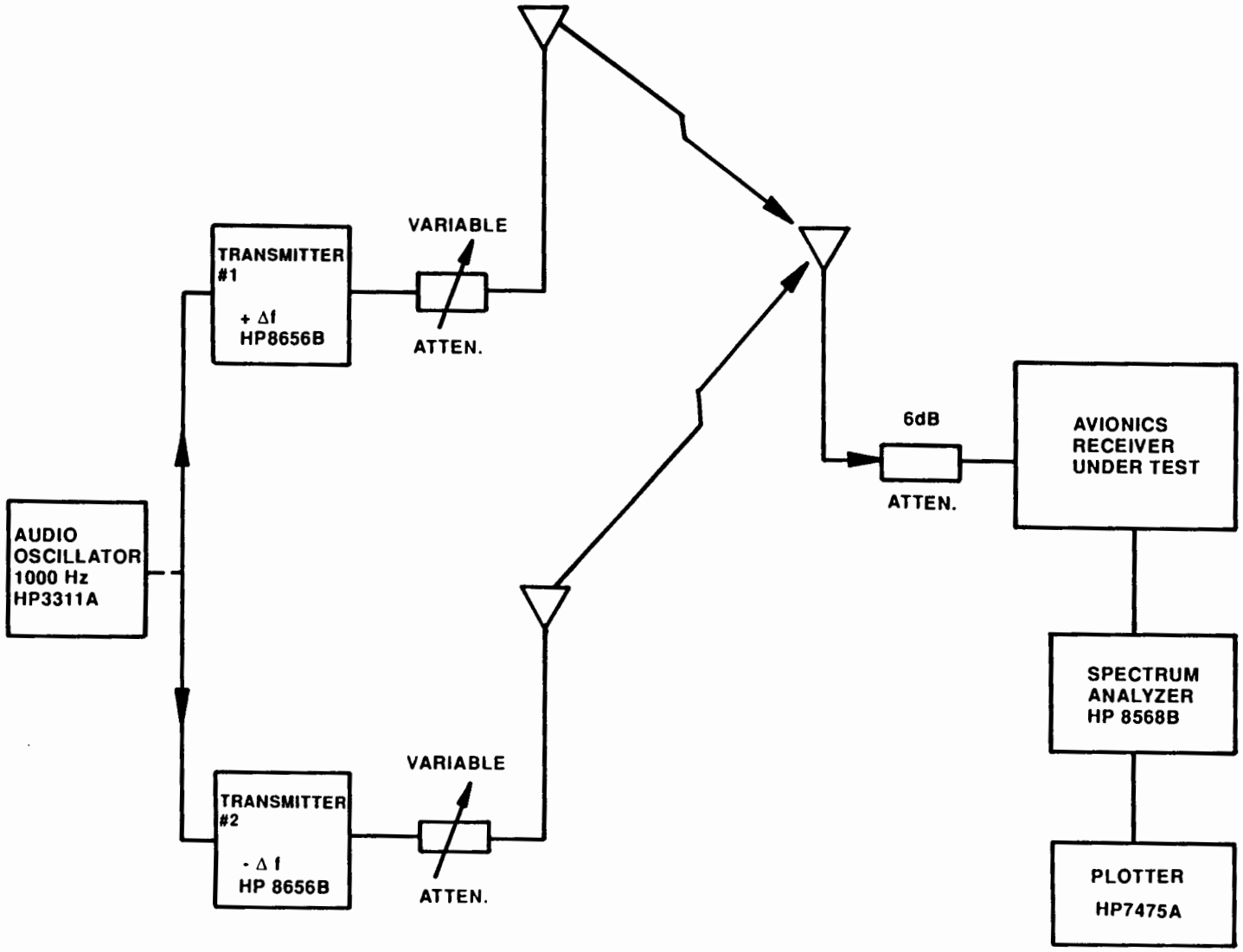

FIGURE 2. TEST SETUP USING AN/GRT-21 TRANSMITTERS

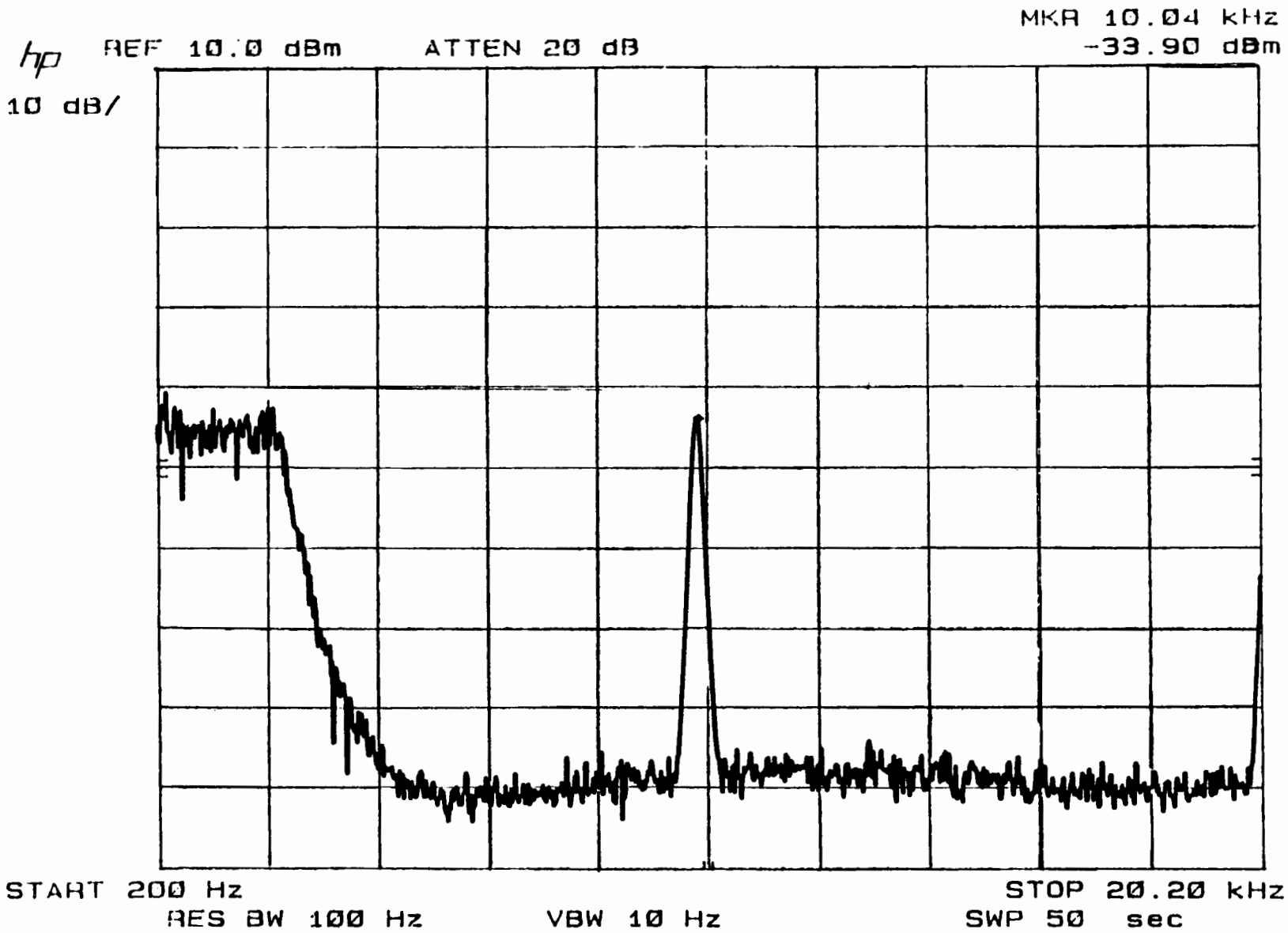

FIGURE 3. RECEIVER 1, +/- 5 kHz OFFSET, NO MODULATION, SIGNAL GENERATOR

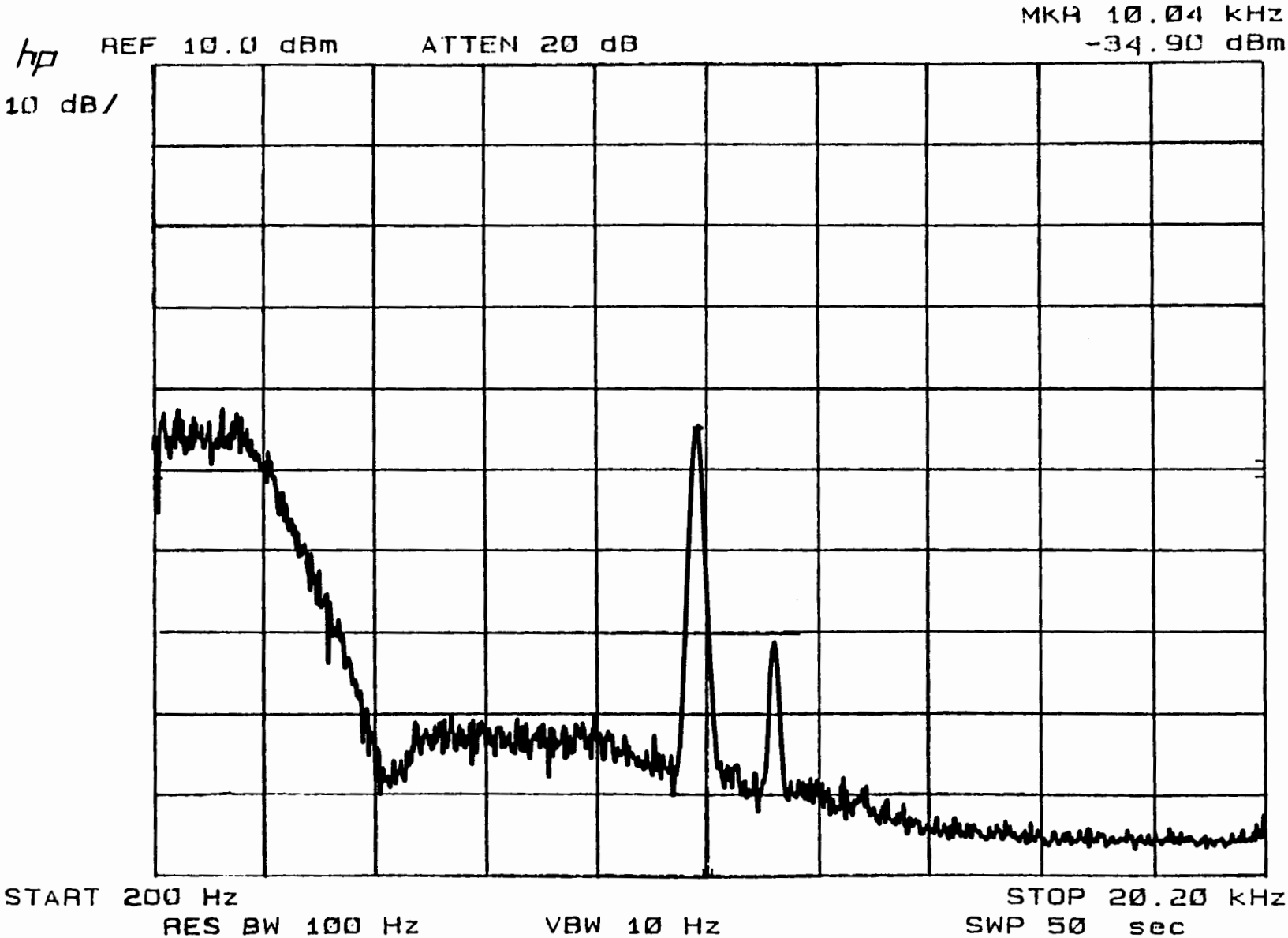

FIGURE 4. RECEIVER 2, +/- 5 kHz, NO MODULATION, SIGNAL GENERATOR

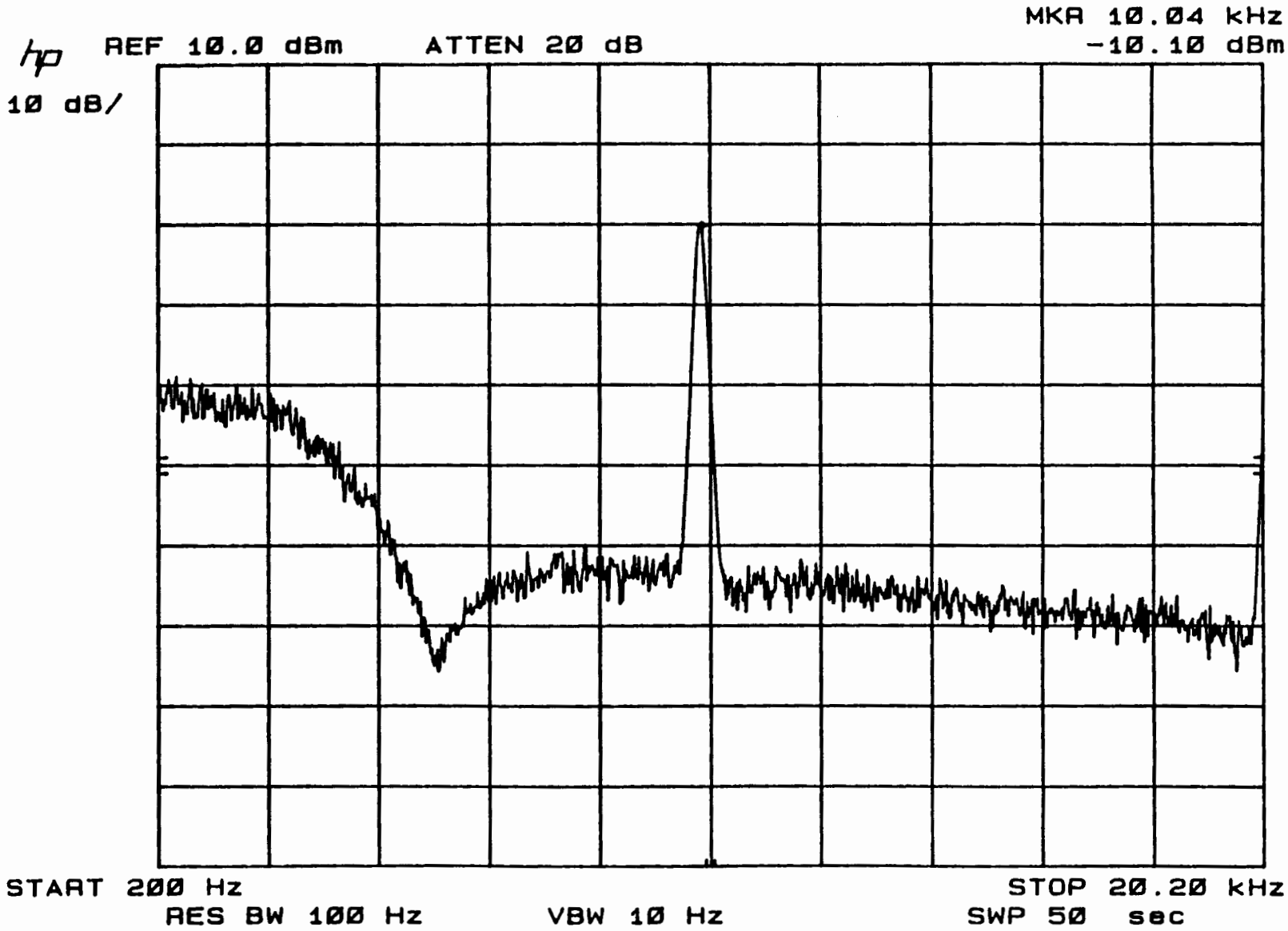

FIGURE 5. RECEIVER 3, +/- 5 kHz, NO MODULATION, SIGNAL GENERATOR

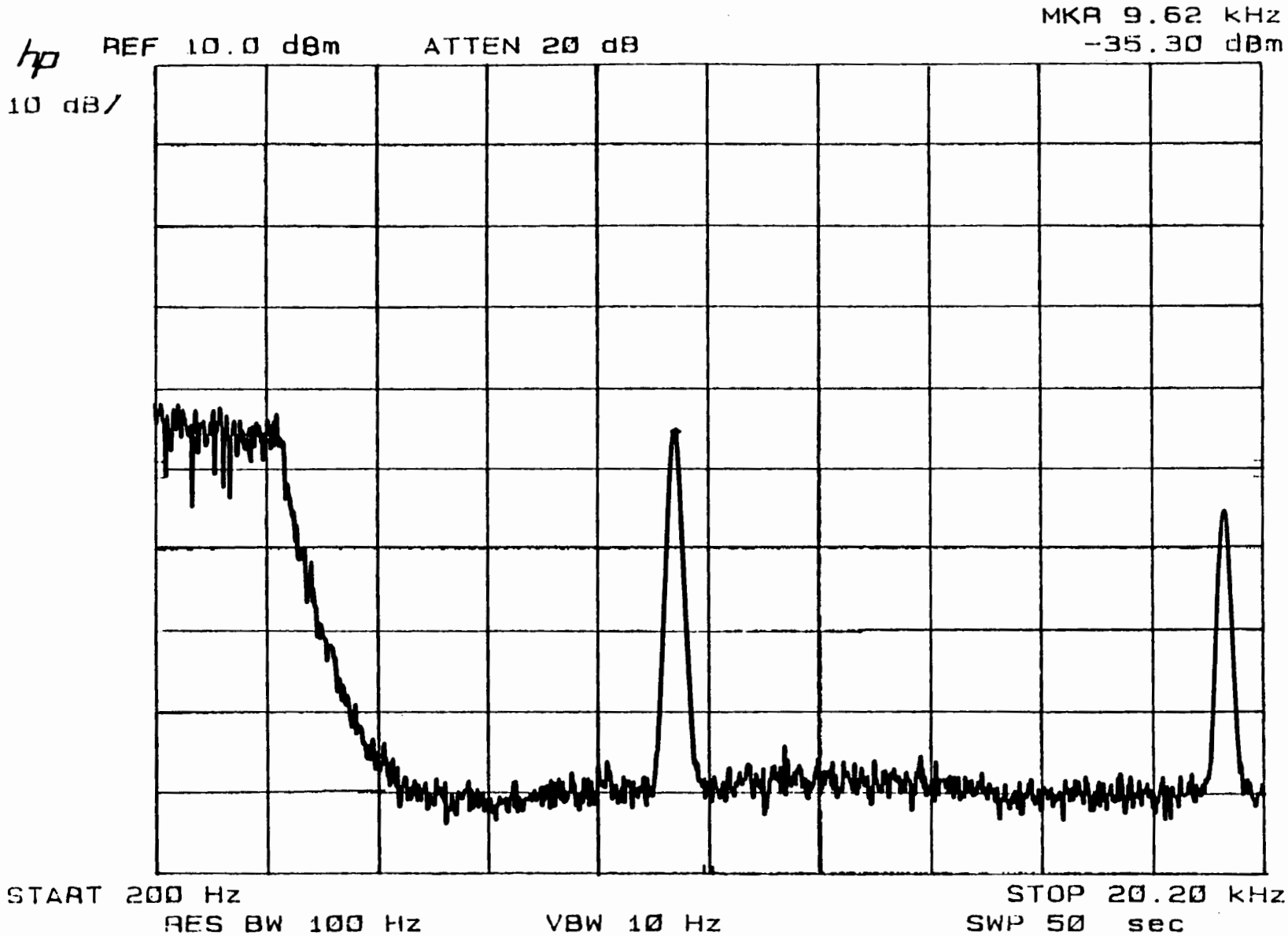

FIGURE 6. RECEIVER 1, +/- 5 kHz, NO MODULATION, TRANSMITTER

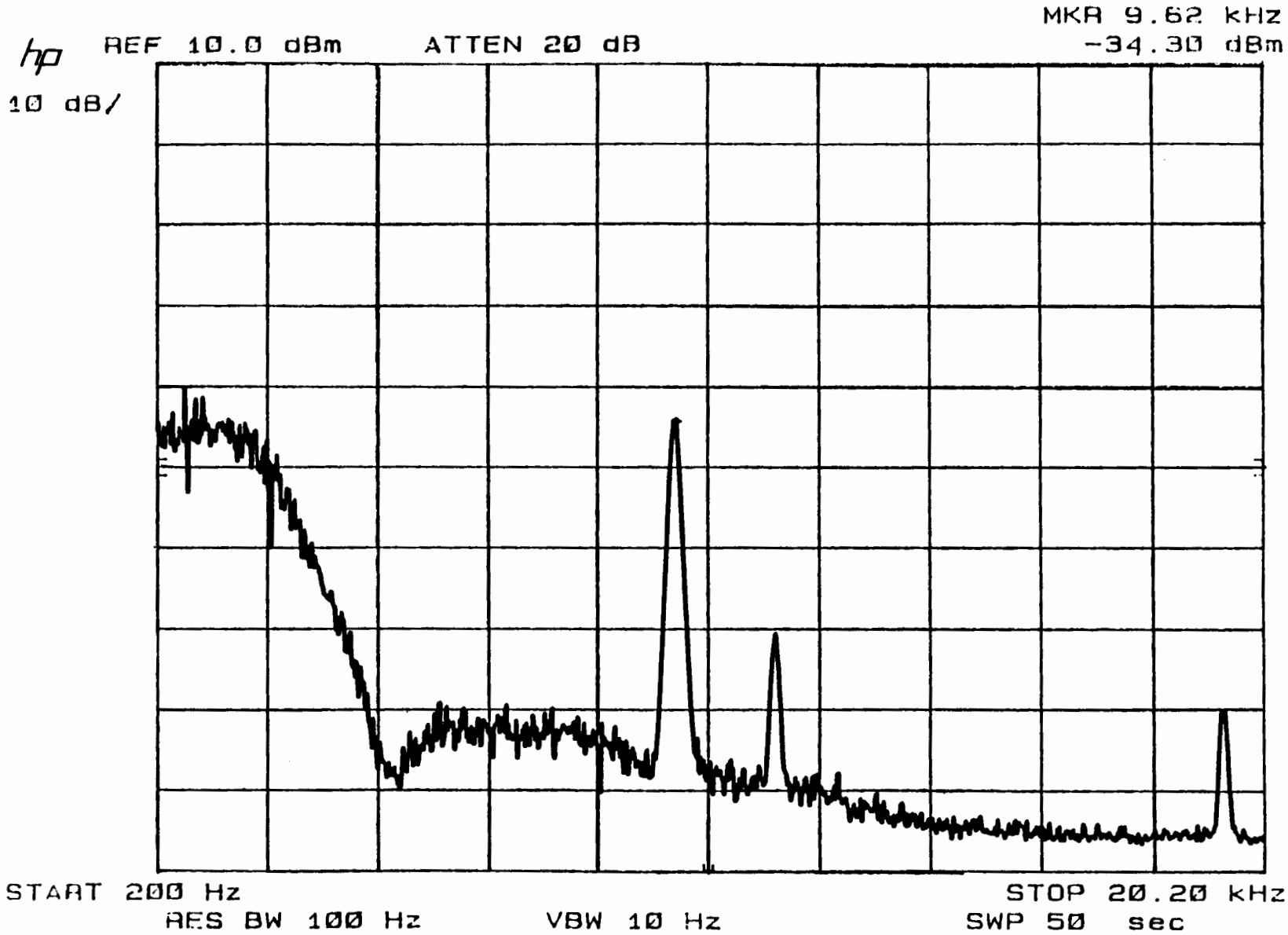

FIGURE 7. RECEIVER 2, +/- 5 kHz, NO MODULATION, TRANSMITTER

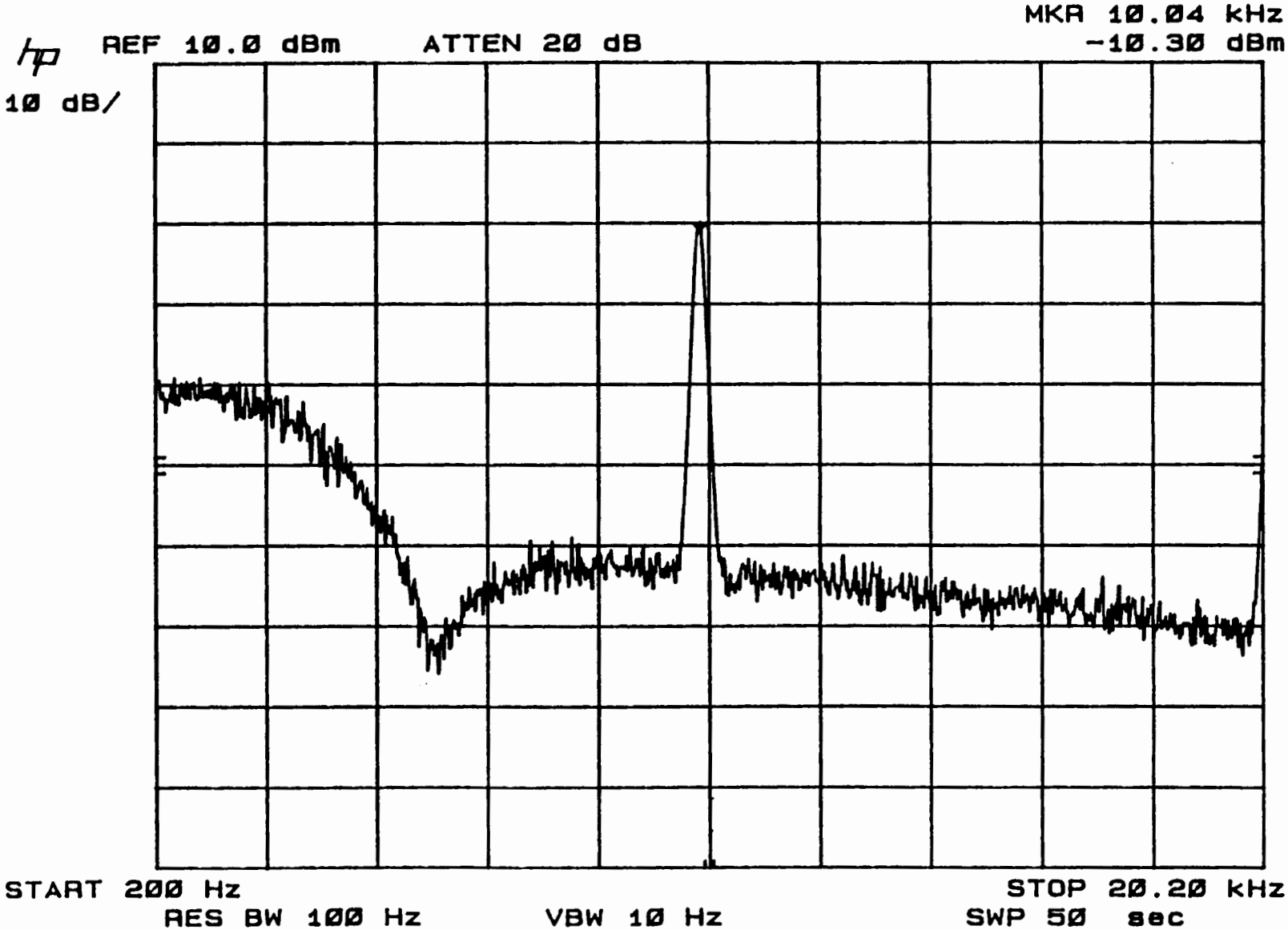

FIGURE 8. RECEIVER 3, +/- 5 kHz, NO MODULATION, TRANSMITTER

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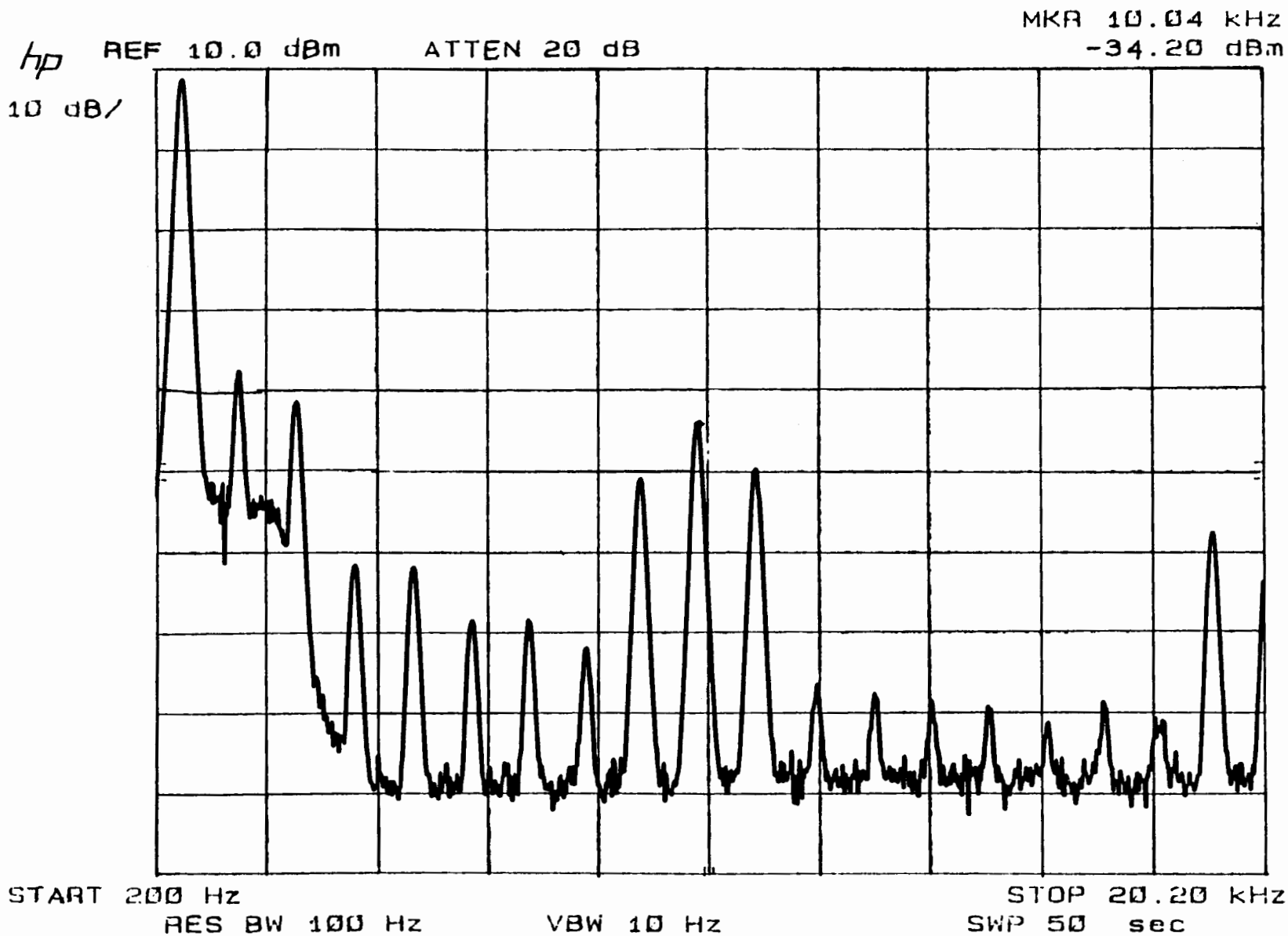

FIGURE 9. RECEIVER 1, +/- 5 kHz, 90-PERCENT TONE, SIGNAL GENERATOR

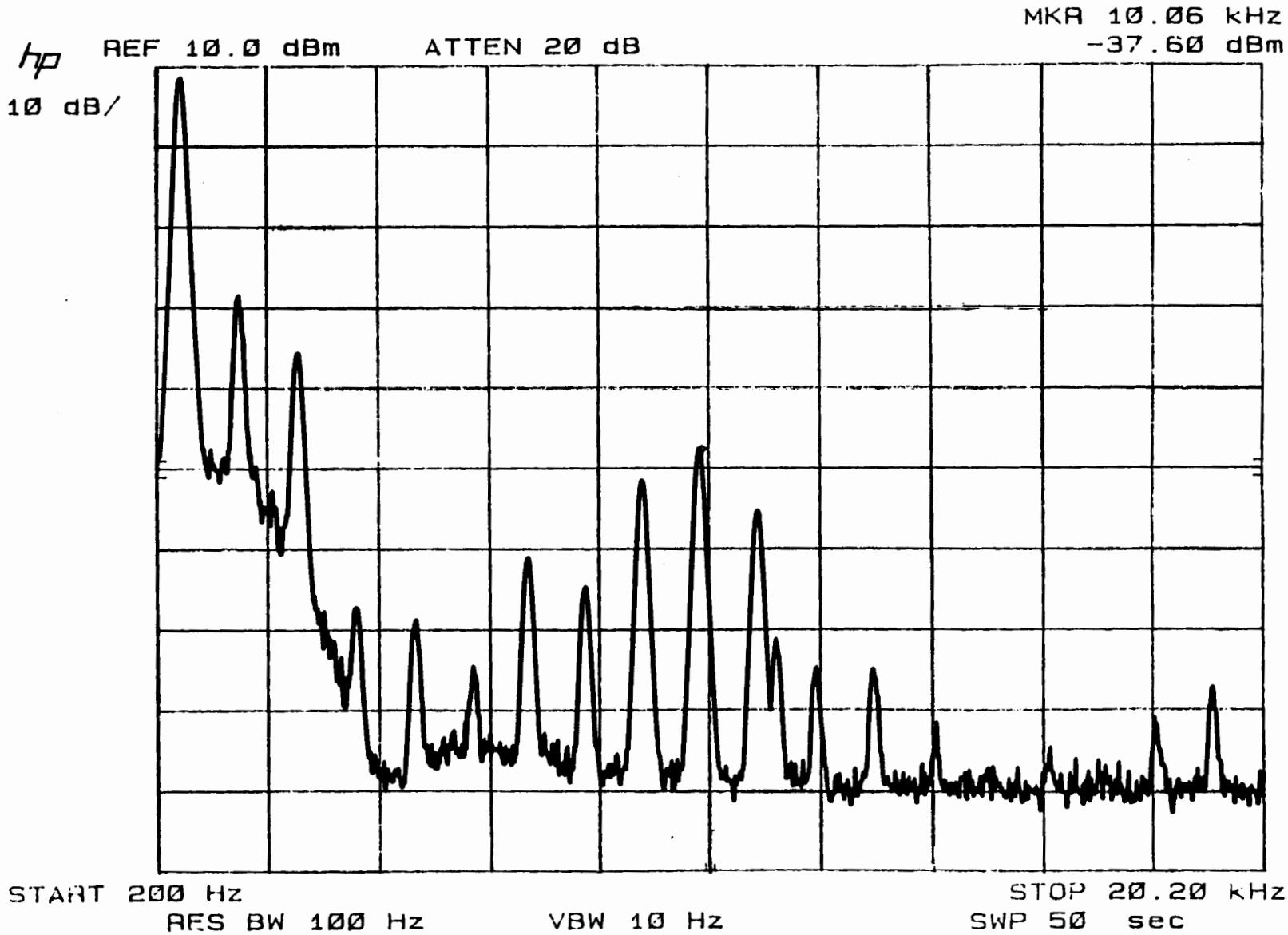

FIGURE 10. RECEIVER 2, +/- 5 kHz, 90-PERCENT TONE, SIGNAL GENERATOR

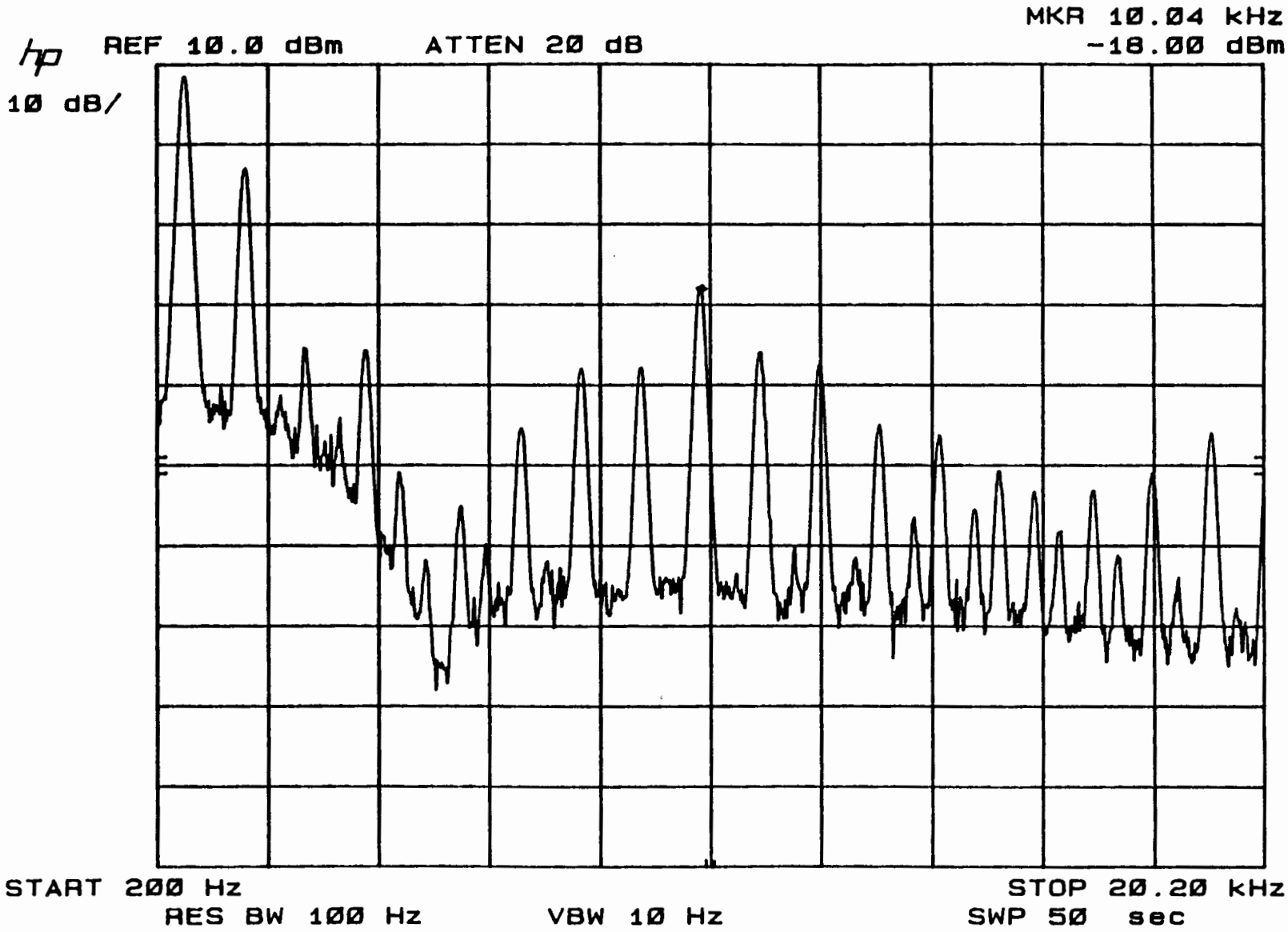

FIGURE 11. RECEIVER 3, +/- 5 kHz, 90-PERCENT TONE, SIGNAL GENERATOR

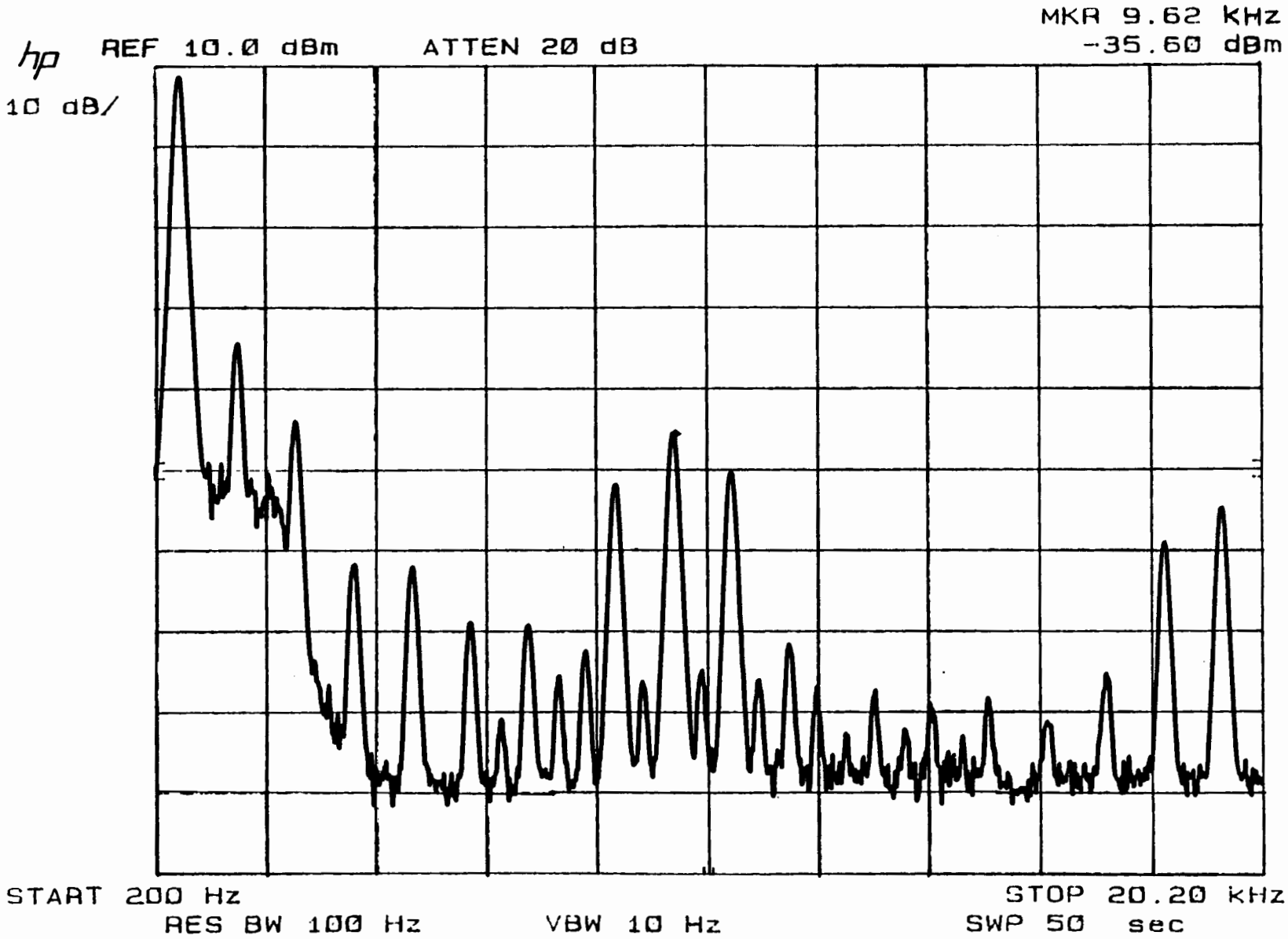

FIGURE 12. RECEIVER 1, +/- 5 kHz, 90-PERCENT TONE, TRANSMITTER

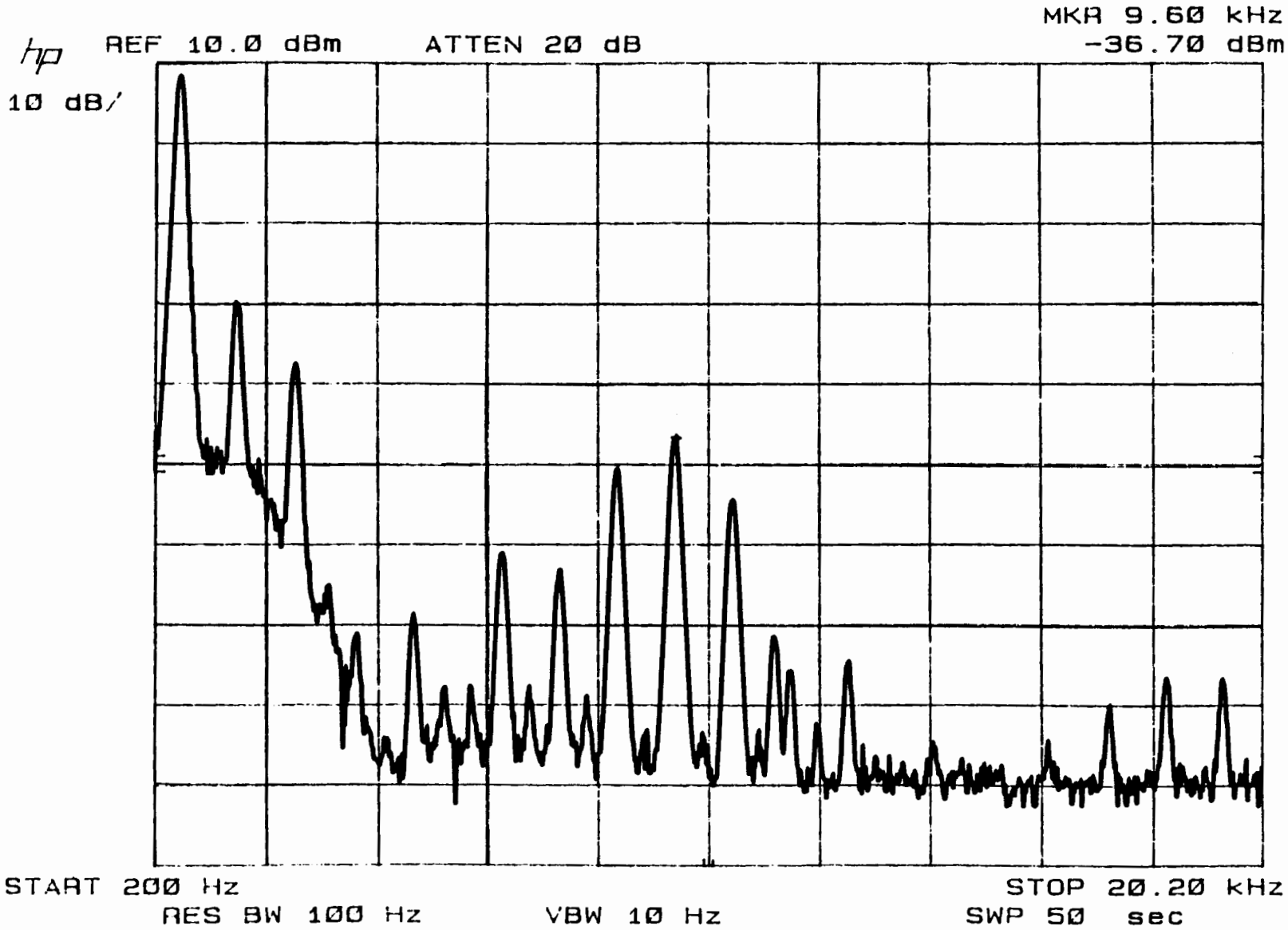

FIGURE 13. RECEIVER 2, +/- 5 kHz, 90-PERCENT TONE, TRANSMITTER

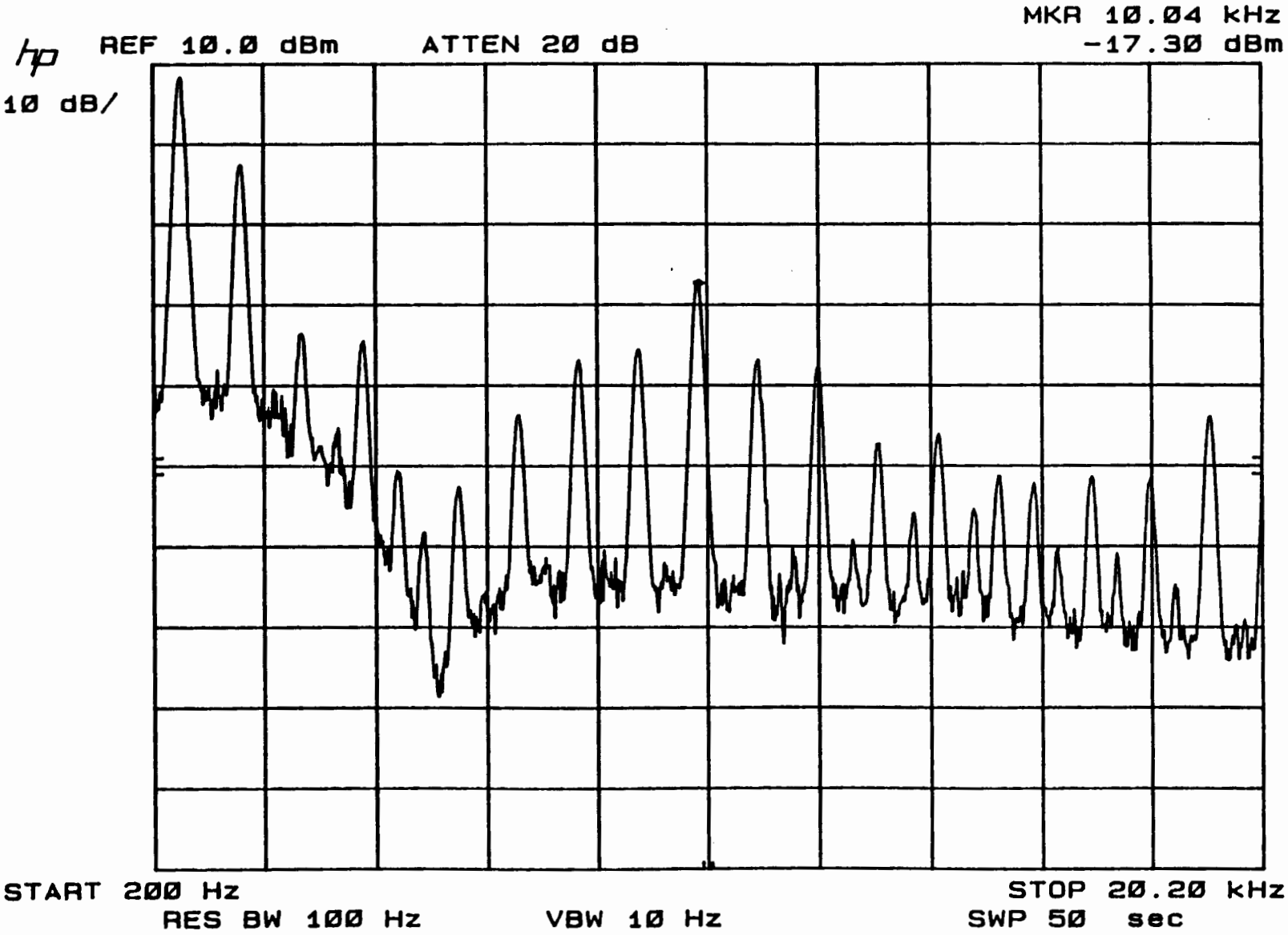

FIGURE 14. RECEIVER 3, +/- 5 kHz, 90-PERCENT TONE, TRANSMITTER

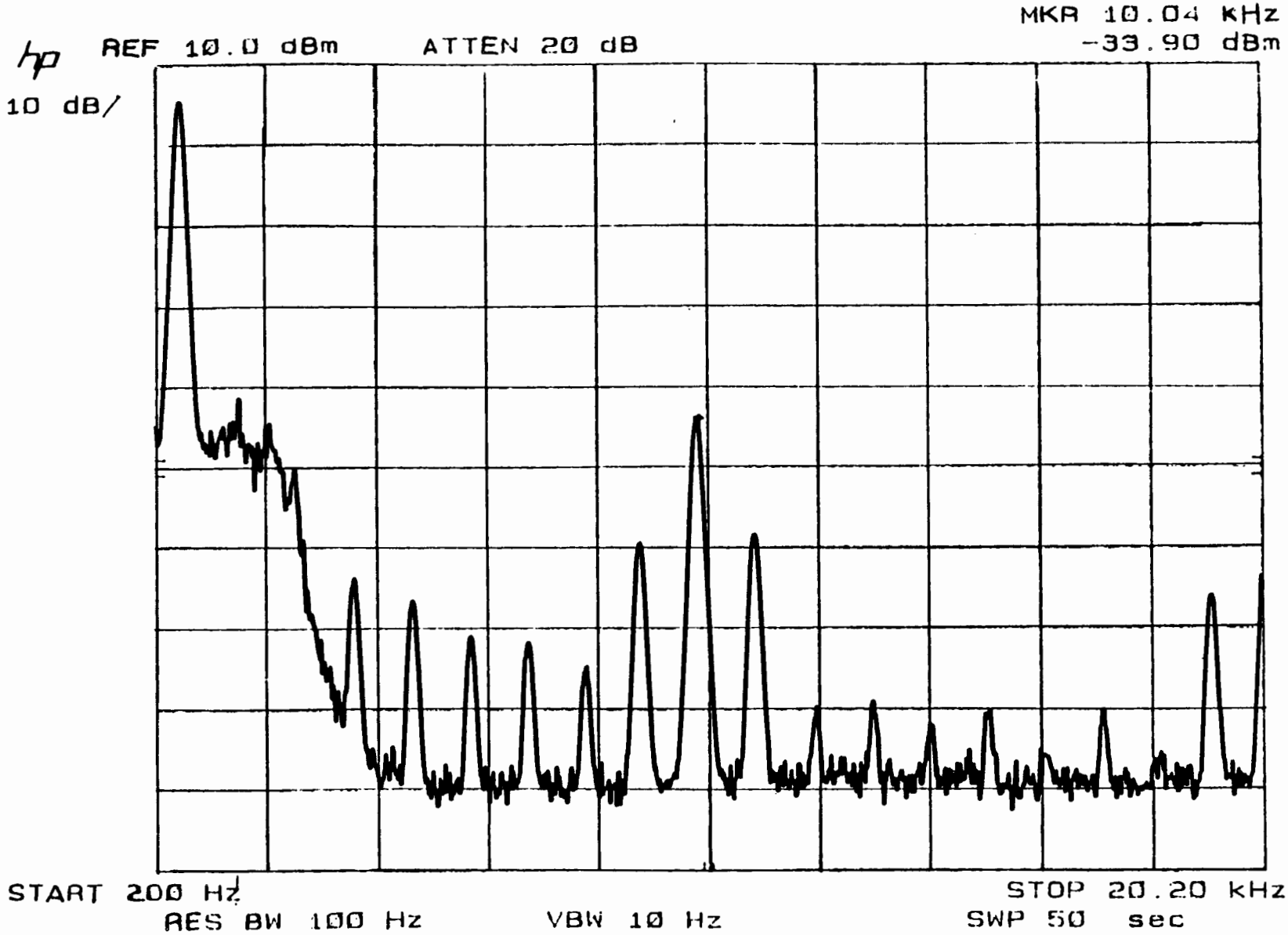

FIGURE 15. RECEIVER 1, +/- 5 kHz, 30-PERCENT TONE, SIGNAL GENERATOR

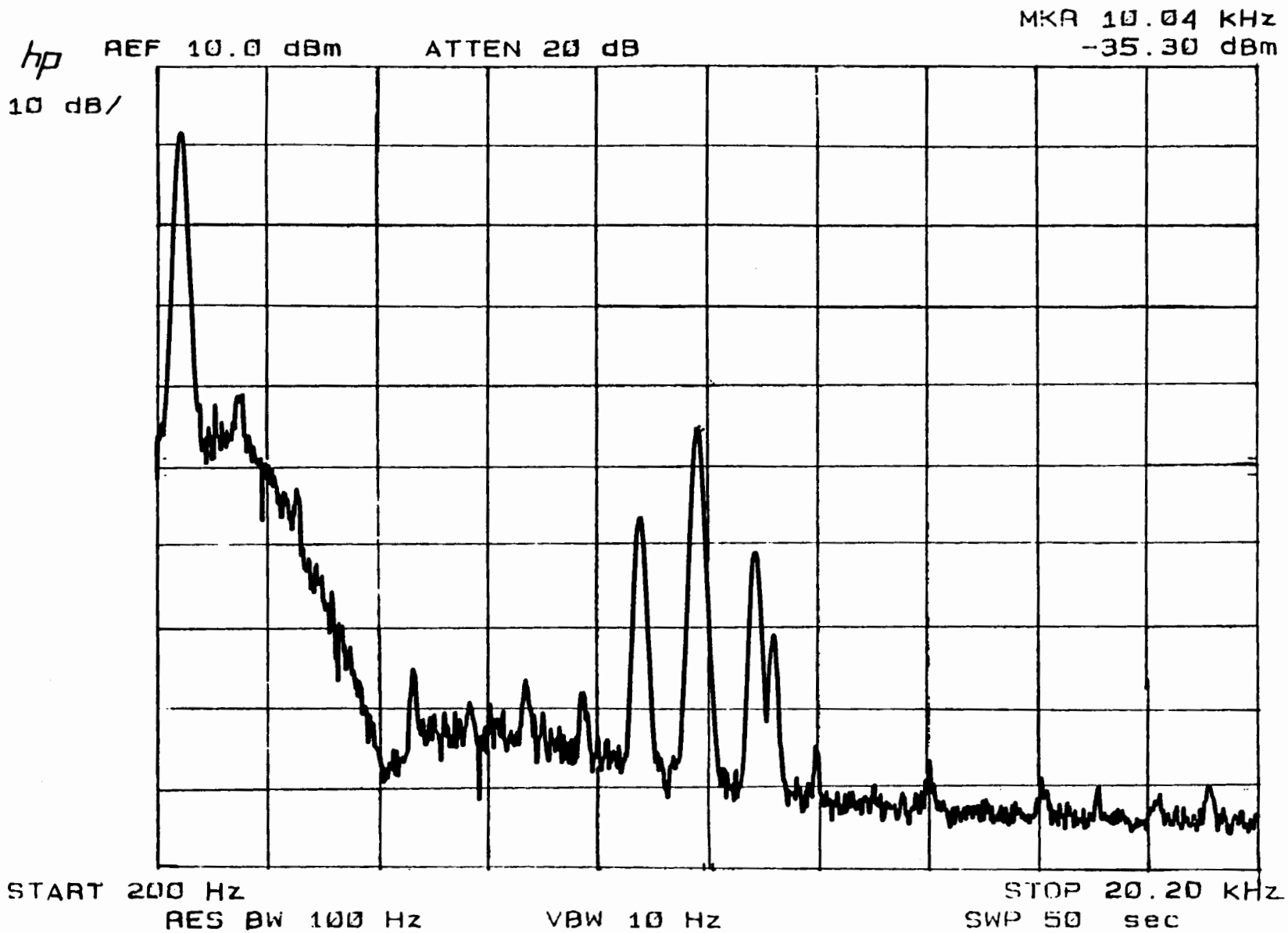

FIGURE 16. RECEIVER 2, +/- 5 kHz, 30-PERCENT TONE, SIGNAL GENERATOR

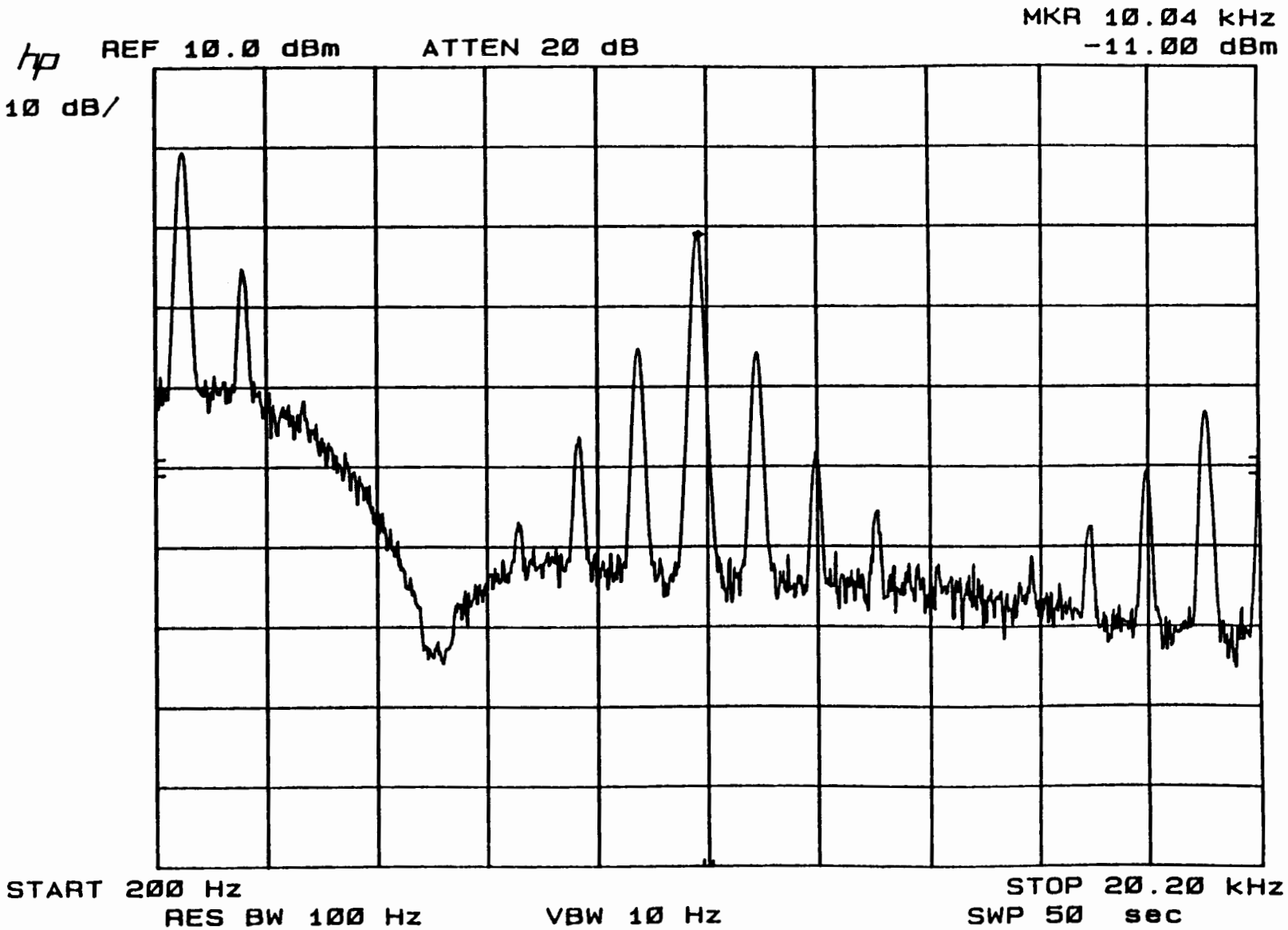

FIGURE 17. RECEIVER 3, +/- 5 kHz, 30-PERCENT TONE, SIGNAL GENERATOR

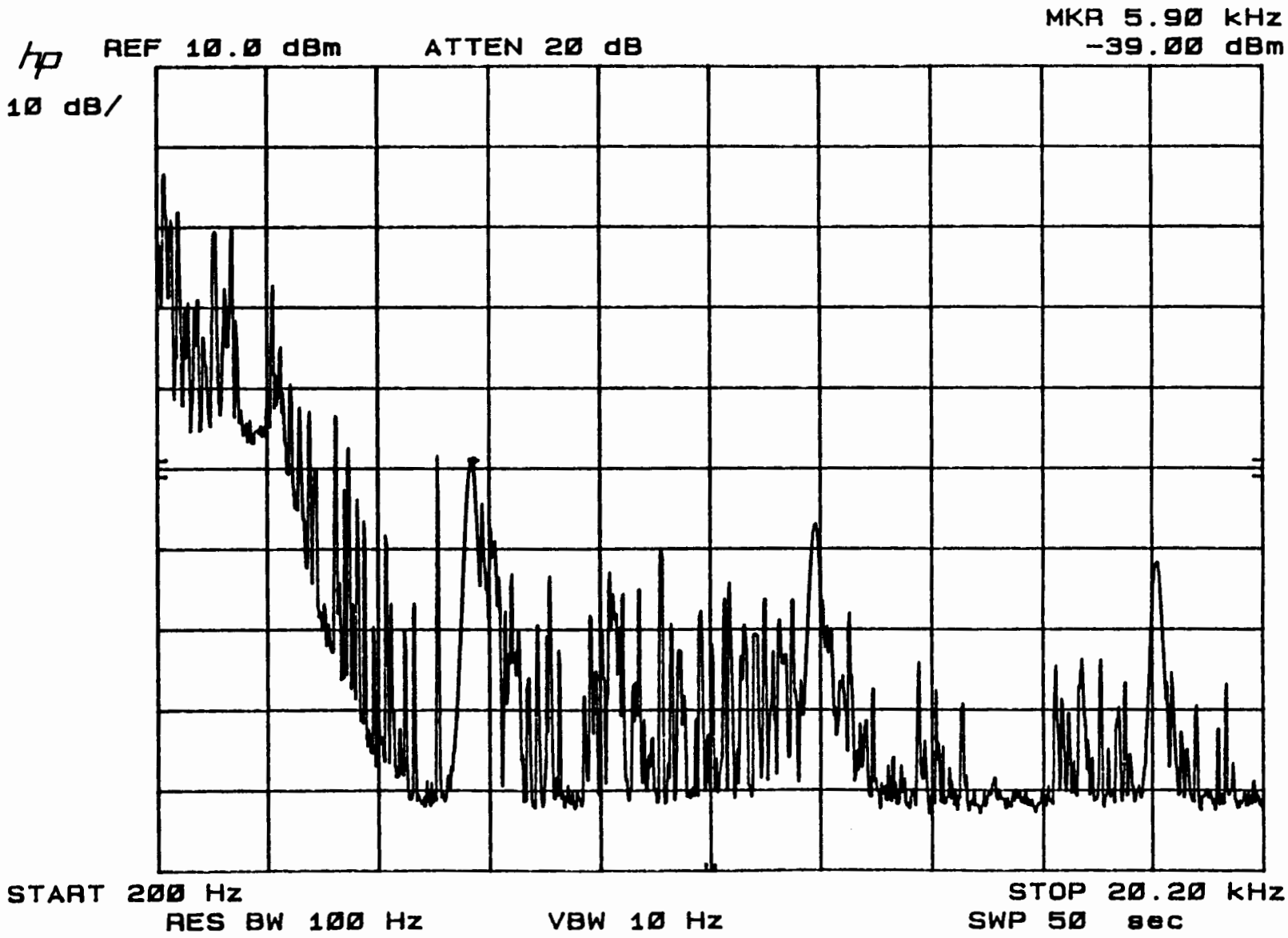

FIGURE 18. RECEIVER 1, +/- 3 kHz, 90-PERCENT VOICE, SIGNAL GENERATOR

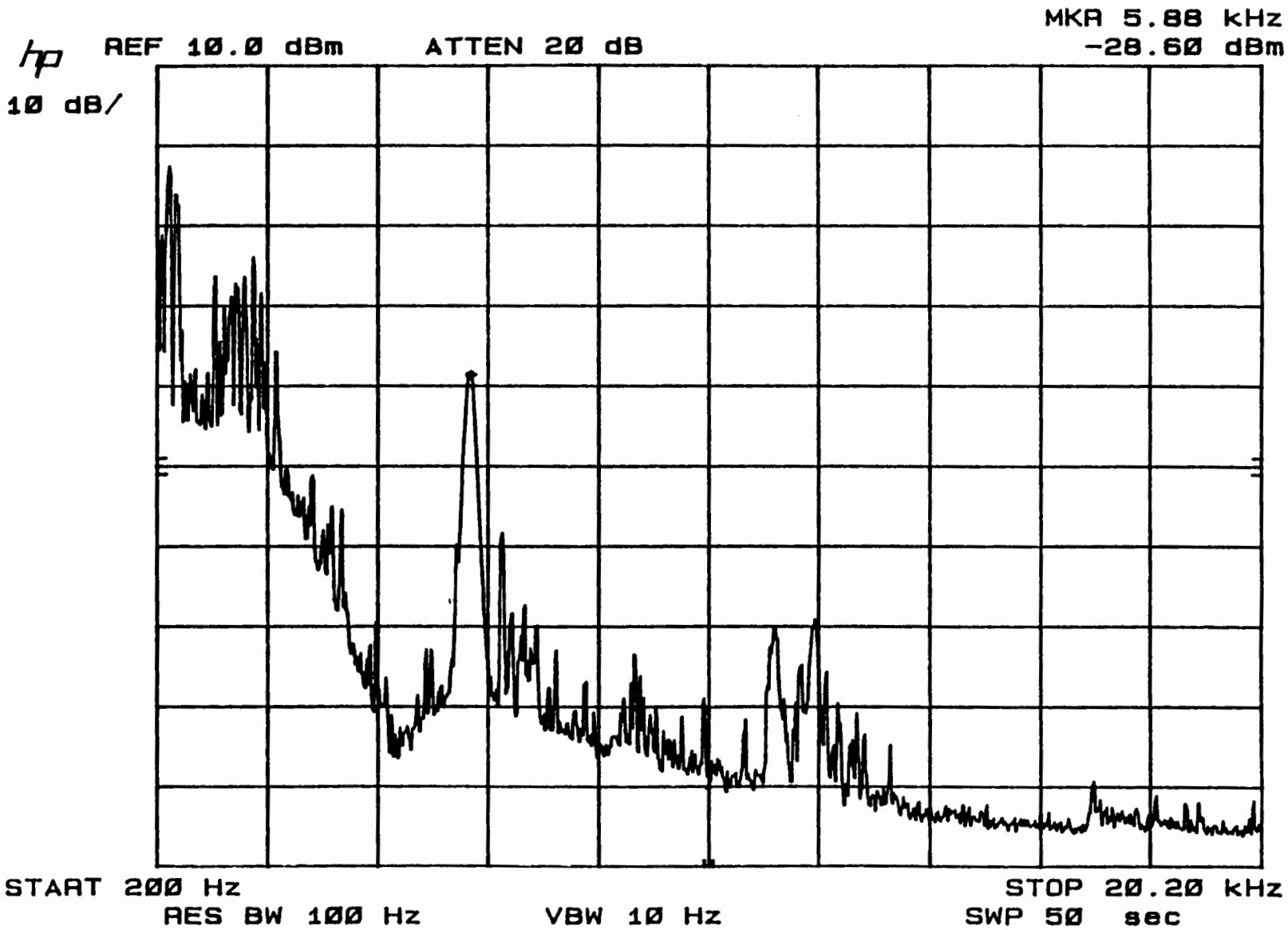

FIGURE 19. RECEIVER 2, +/- 3 kHz, 90-PERCENT VOICE, SIGNAL GENERATOR

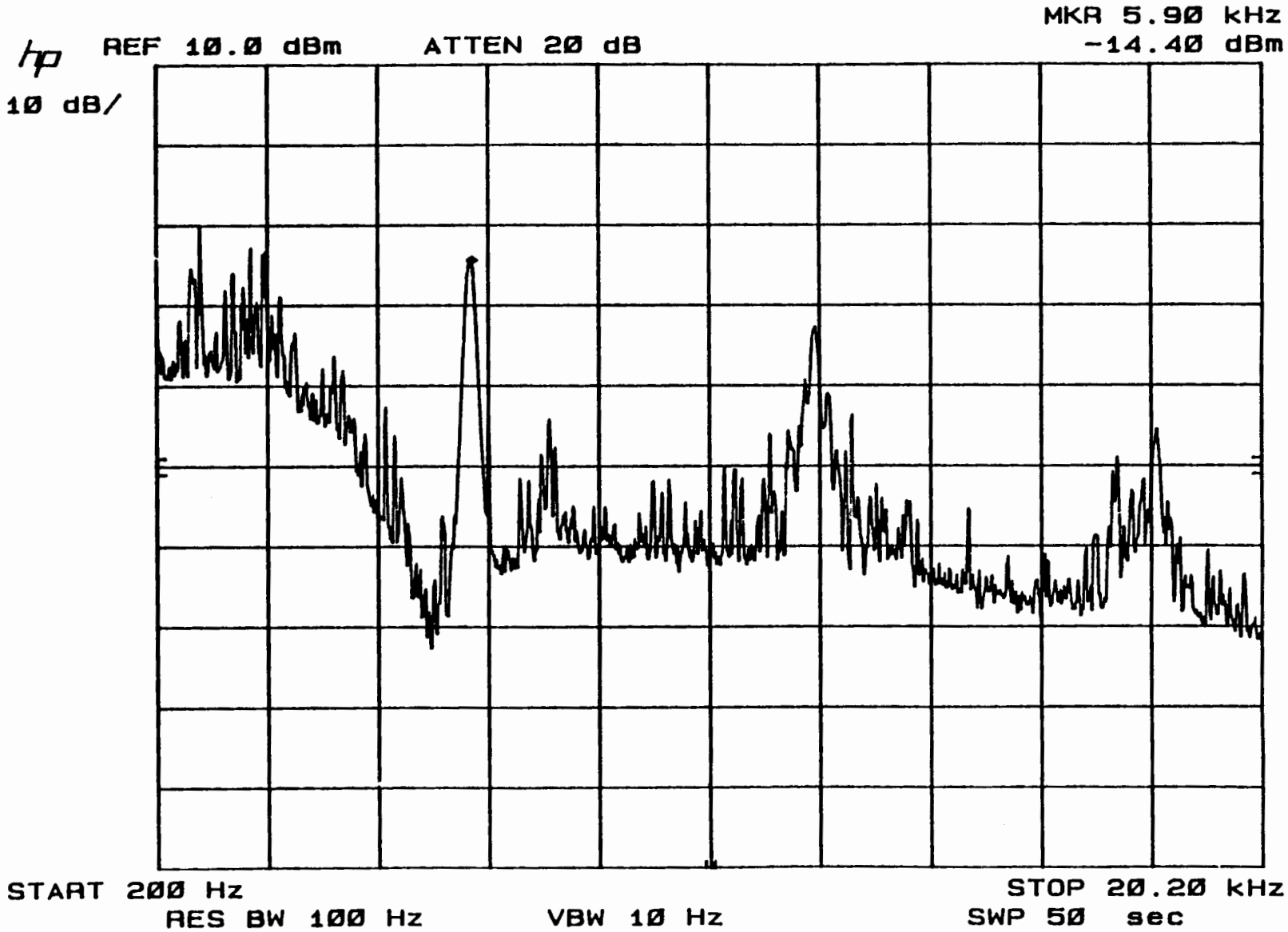

FIGURE 20. RECEIVER 3, +/- 3 kHz, 90-PERCENT VOICE, SIGNAL GENERATOR

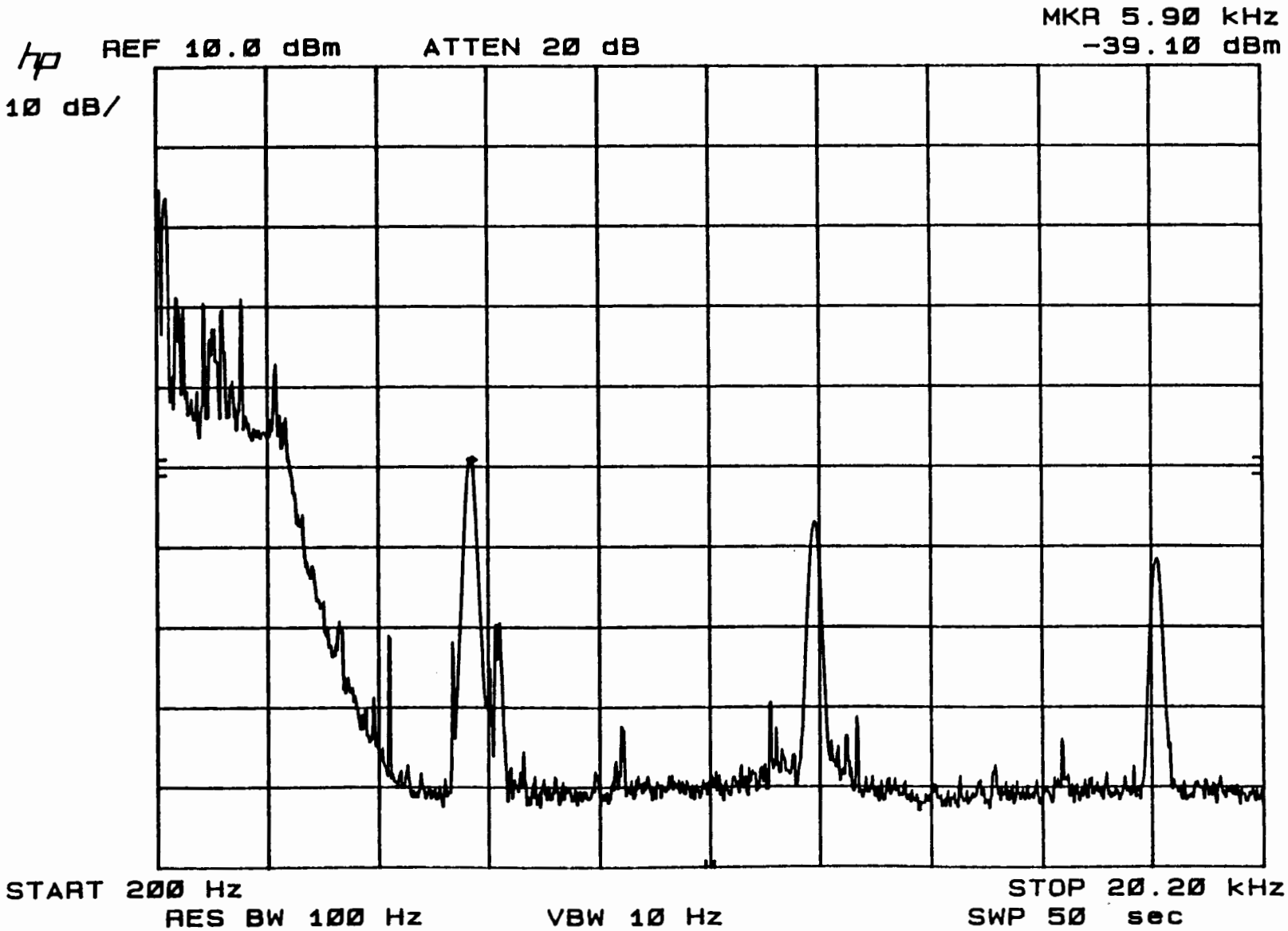

FIGURE 21. RECEIVER 1, +/- 3 kHz, 30-PERCENT VOICE, SIGNAL GENERATOR

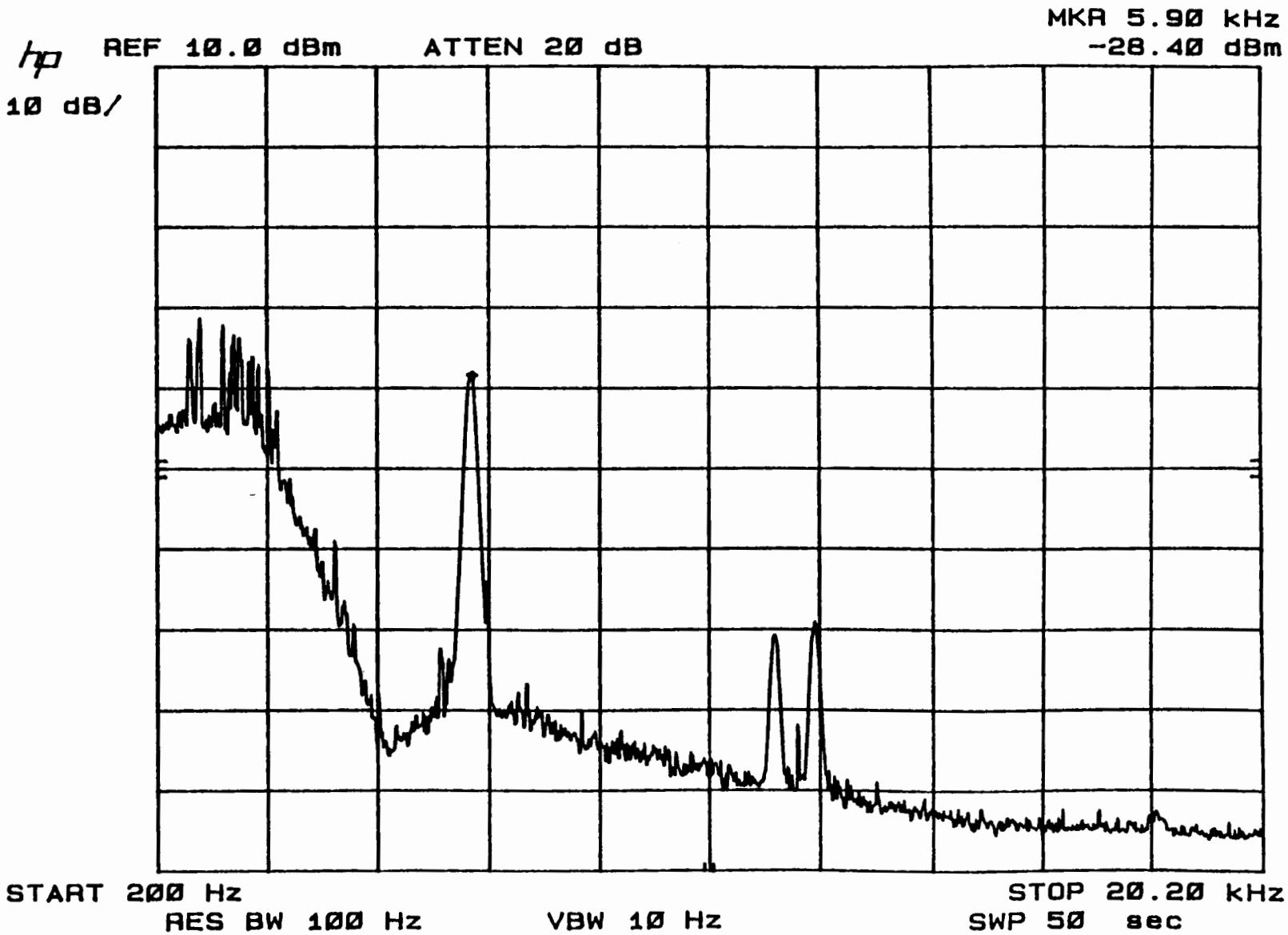

FIGURE 22. RECEIVER 2, +/- 3 kHz, 30-PERCENT VOICE, SIGNAL GENERATOR

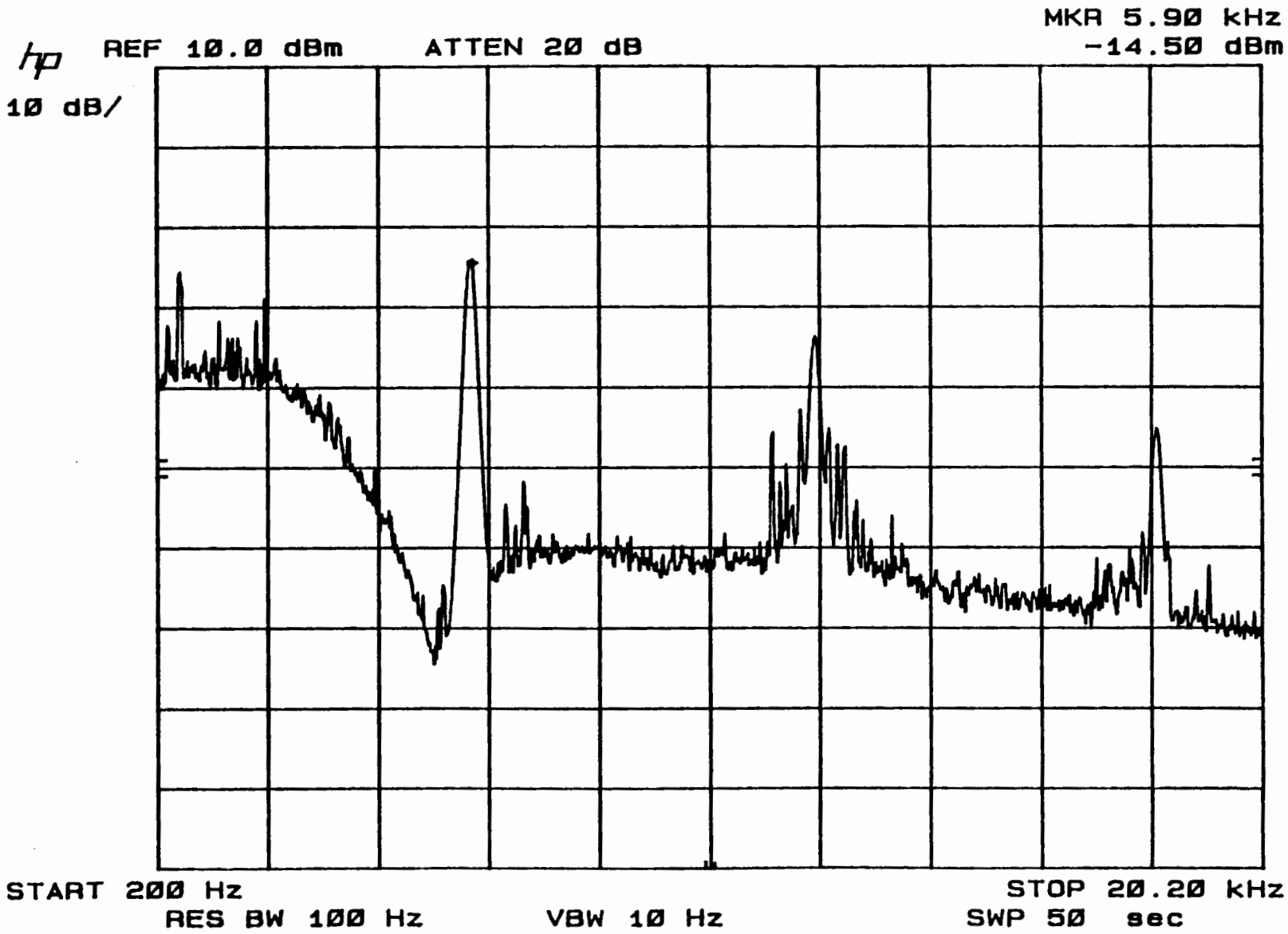

FIGURE 23. RECEIVER 3, +/- 3 kHz, 30-PERCENT VOICE, SIGNAL GENERATOR

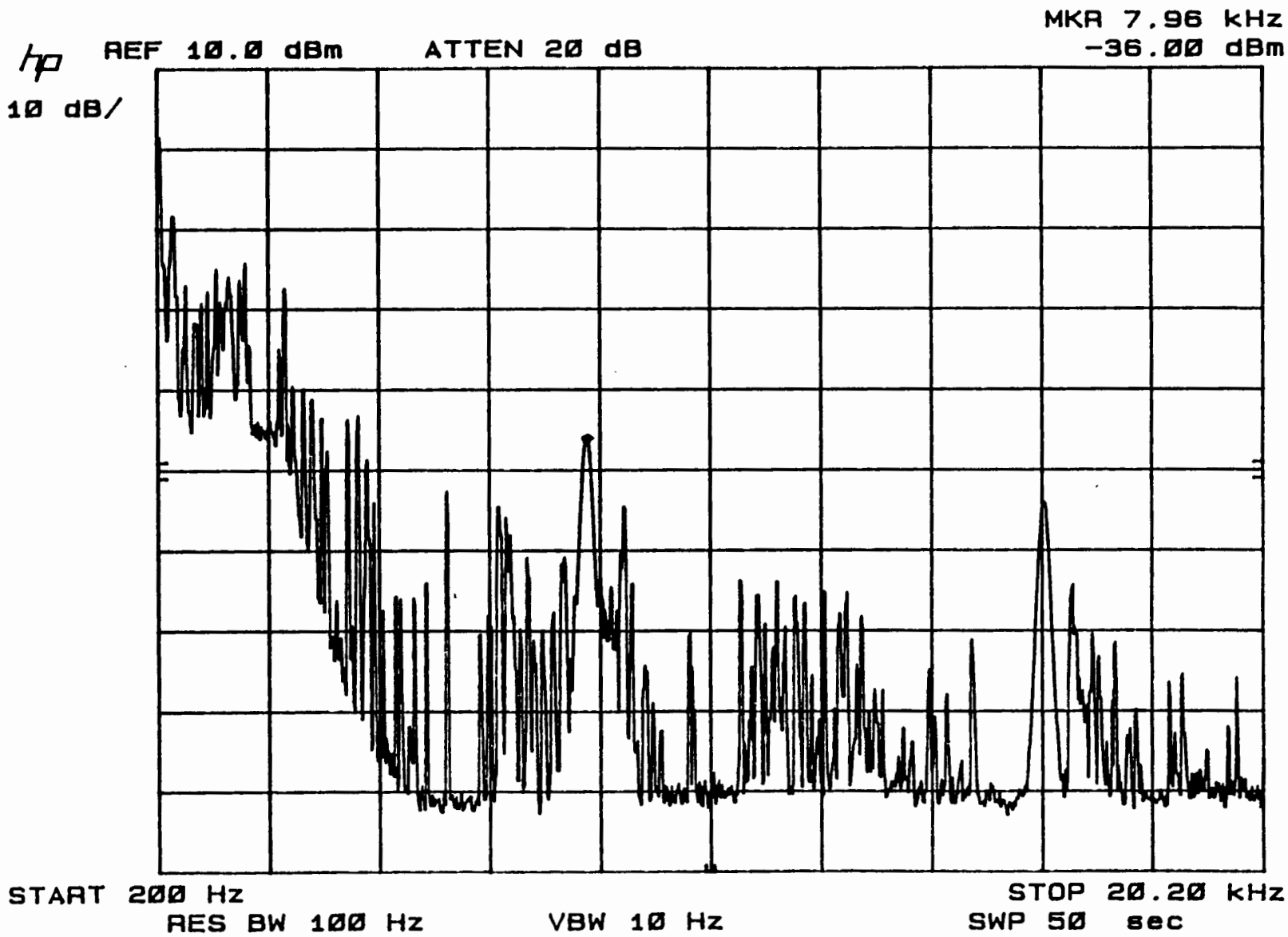

FIGURE 24. RECEIVER 1, +/- 4 kHz, 90-PERCENT VOICE, SIGNAL GENERATOR

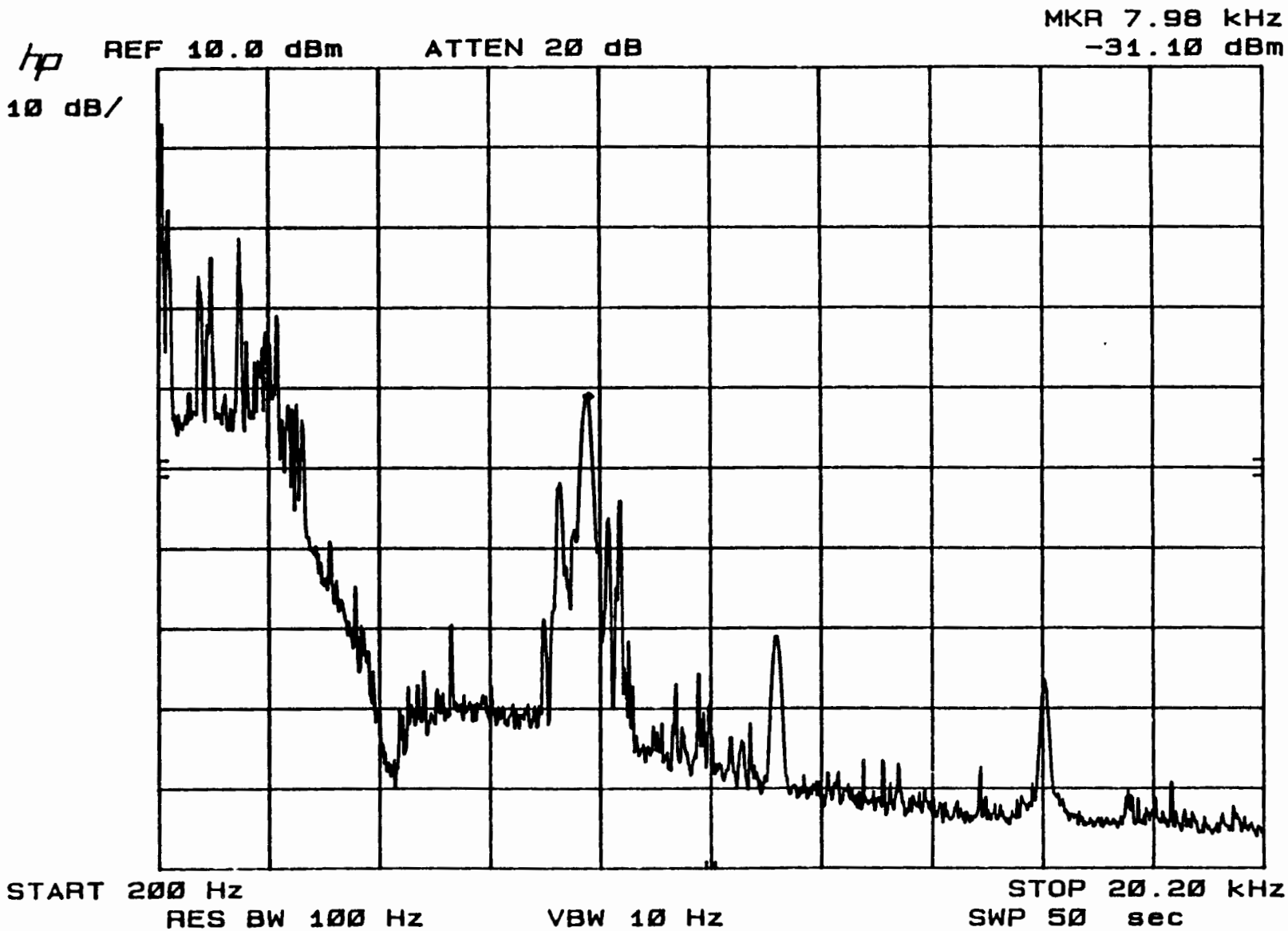

FIGURE 25. RECEIVER 2, +/- 4 kHz, 90-PERCENT VOICE, SIGNAL GENERATOR

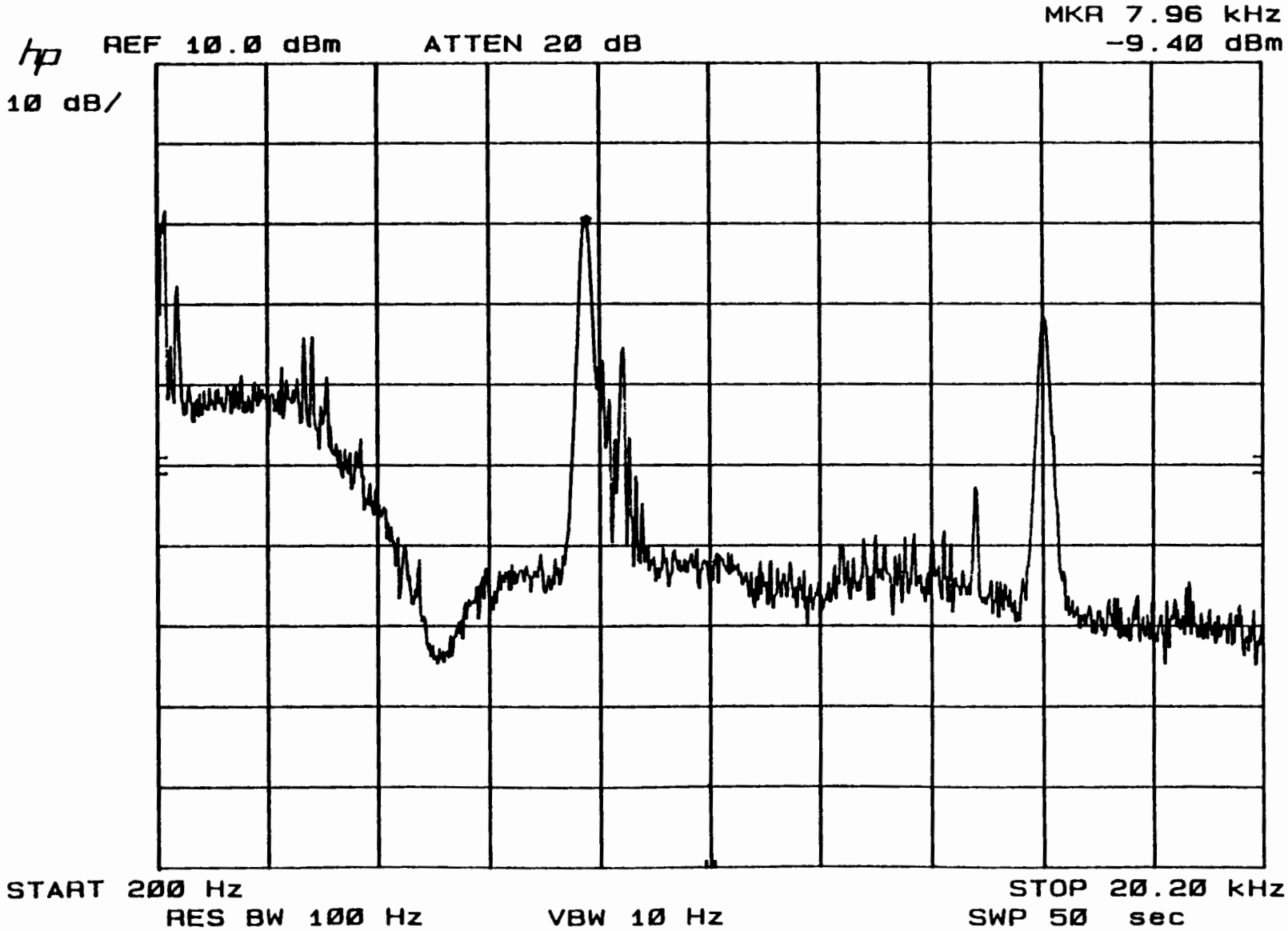

FIGURE 26. RECEIVER 3, +/- 4 kHz, 90-PERCENT VOICE, SIGNAL GENERATOR

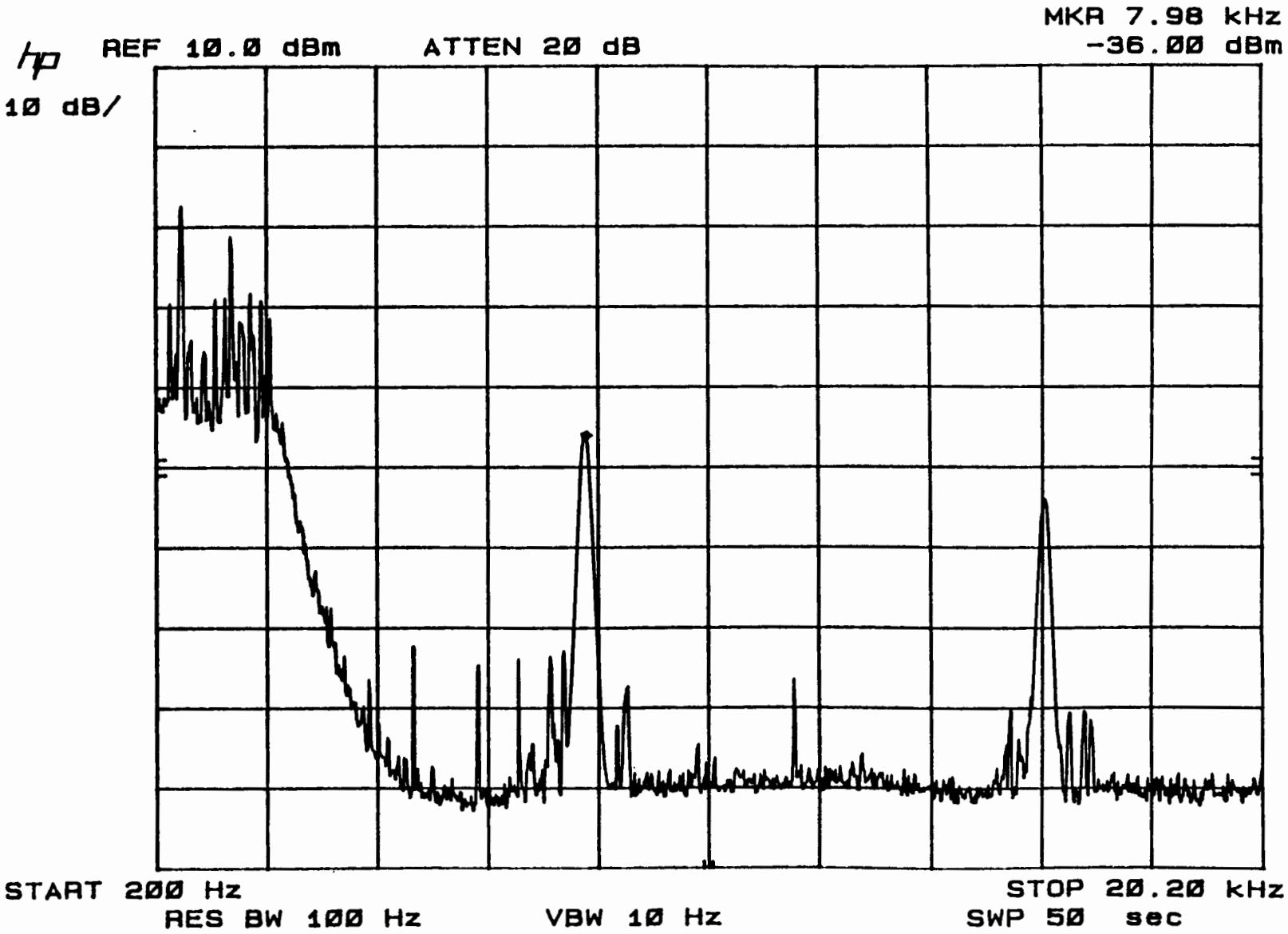

FIGURE 27. RECEIVER 1, +/- 4 kHz, 30-PERCENT VOICE, SIGNAL GENERATOR

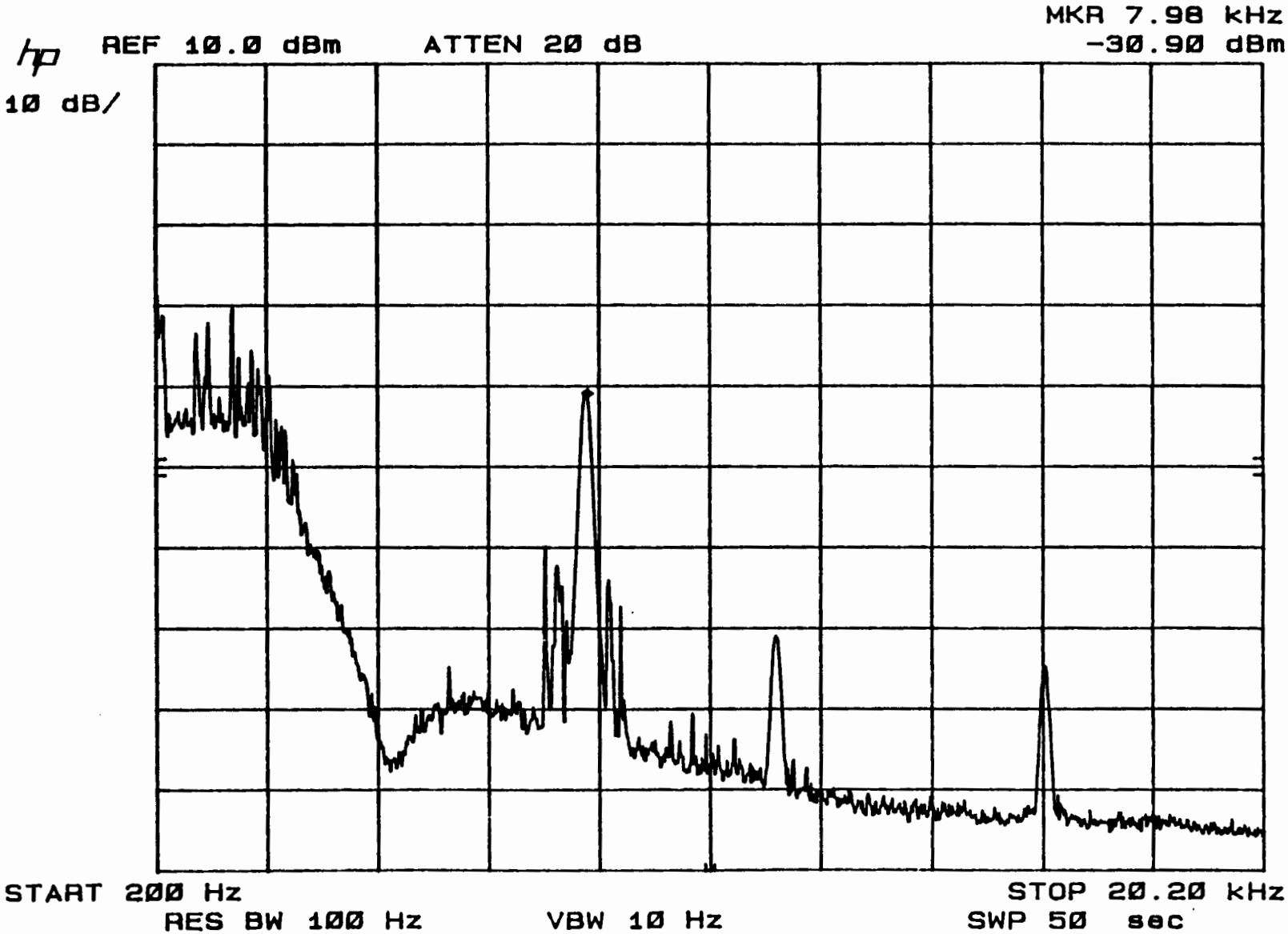

FIGURE 28. RECEIVER 2, +/- 4 kHz, 30-PERCENT VOICE, SIGNAL GENERATOR

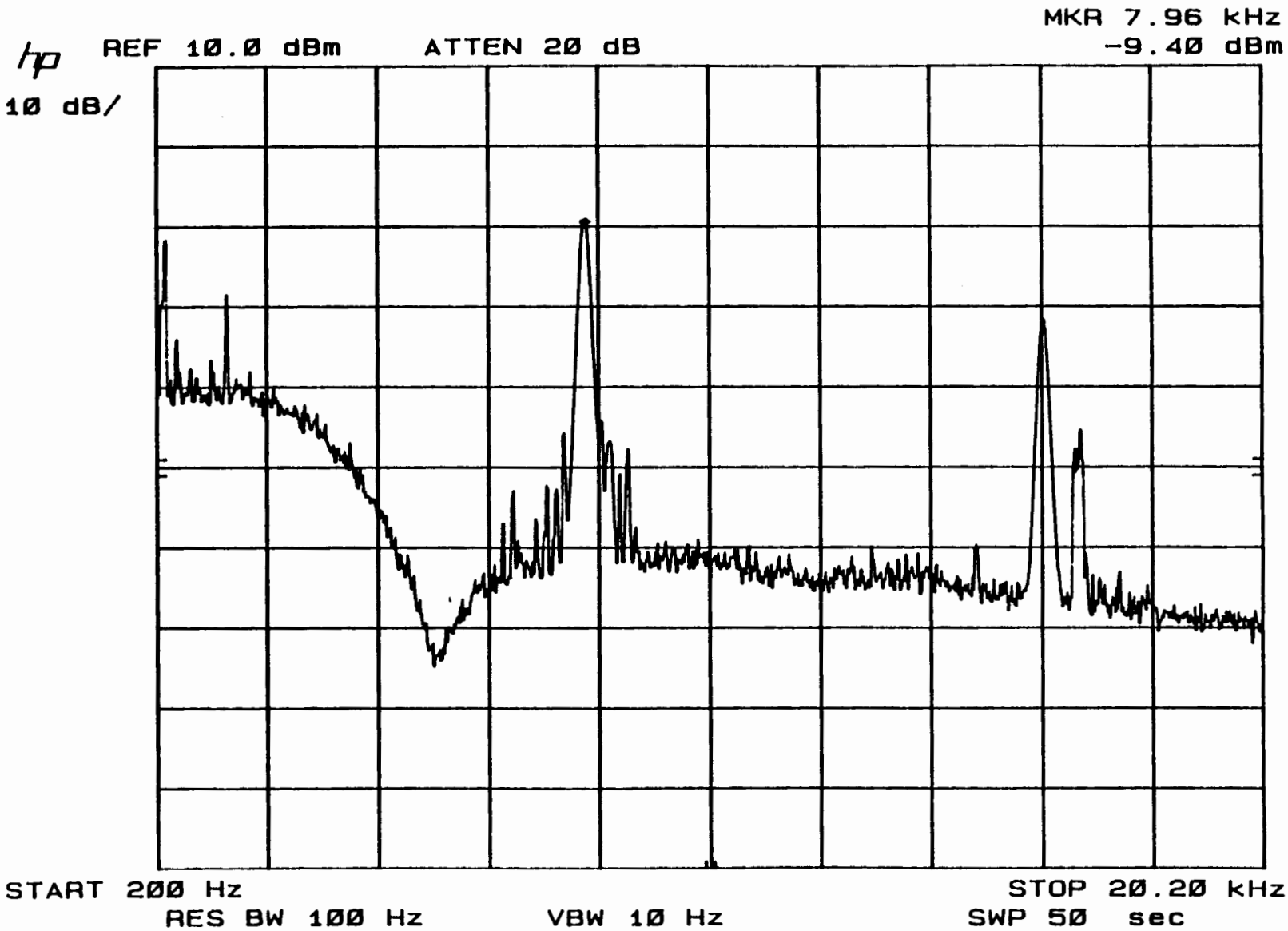

FIGURE 29. RECEIVER 3, +/- 4 kHz, 30-PERCENT VOICE, SIGNAL GENERATOR

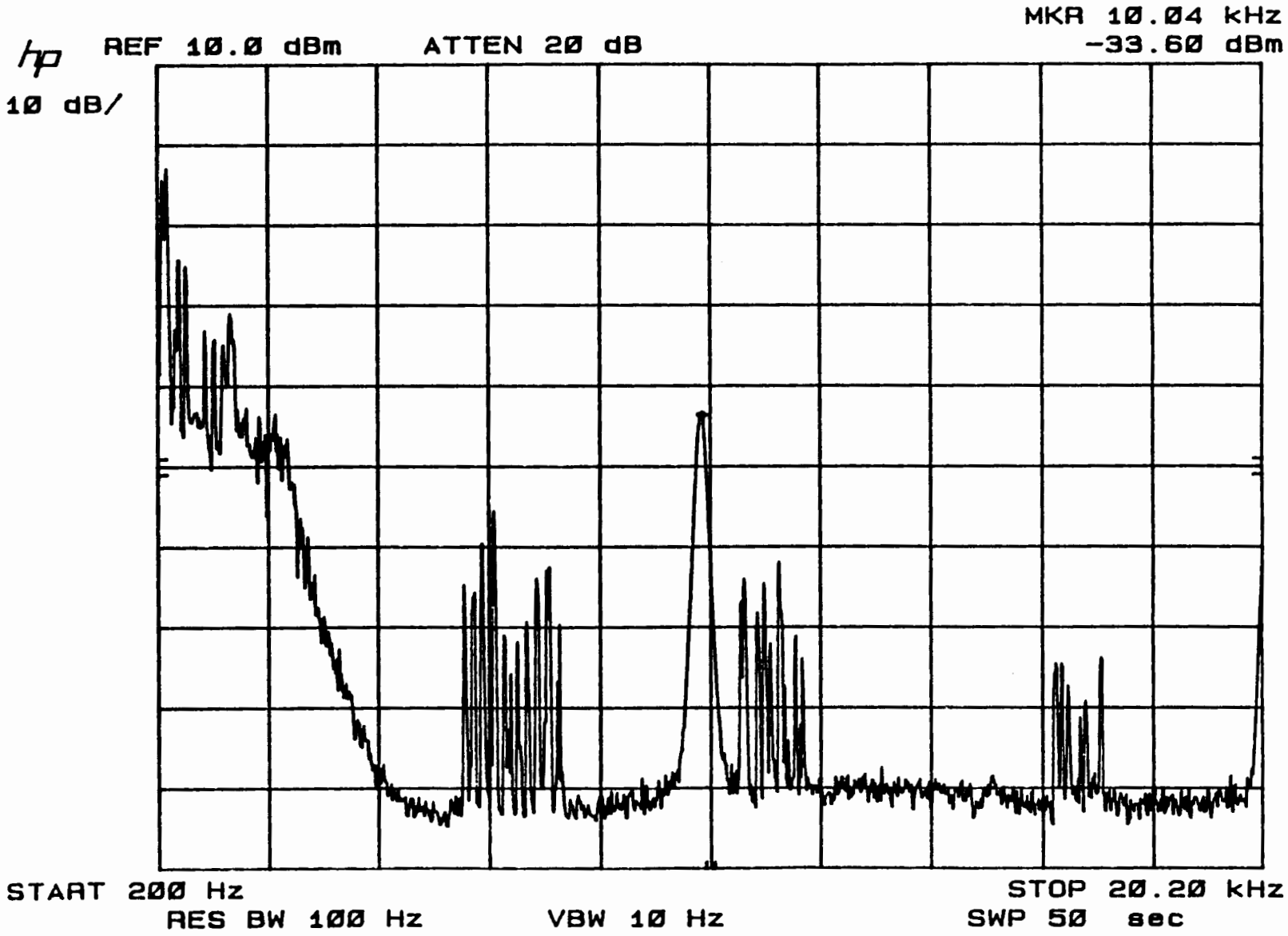

FIGURE 30. RECEIVER 1, +/- 5 kHz, 90-PERCENT VOICE, SIGNAL GENERATOR

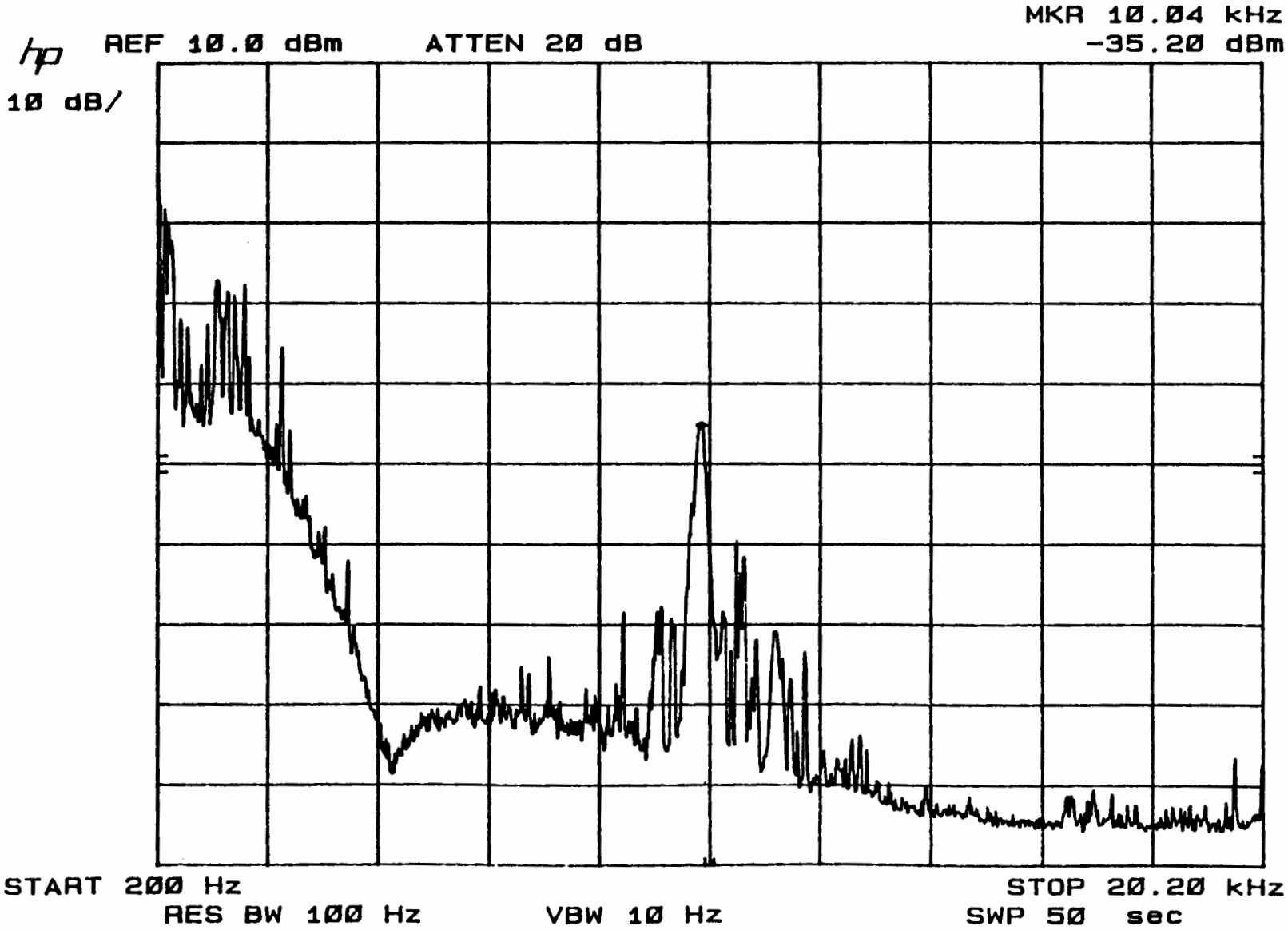

FIGURE 31. RECEIVER 2, +/- 5 kHz, 90-PERCENT VOICE, SIGNAL GENERATOR

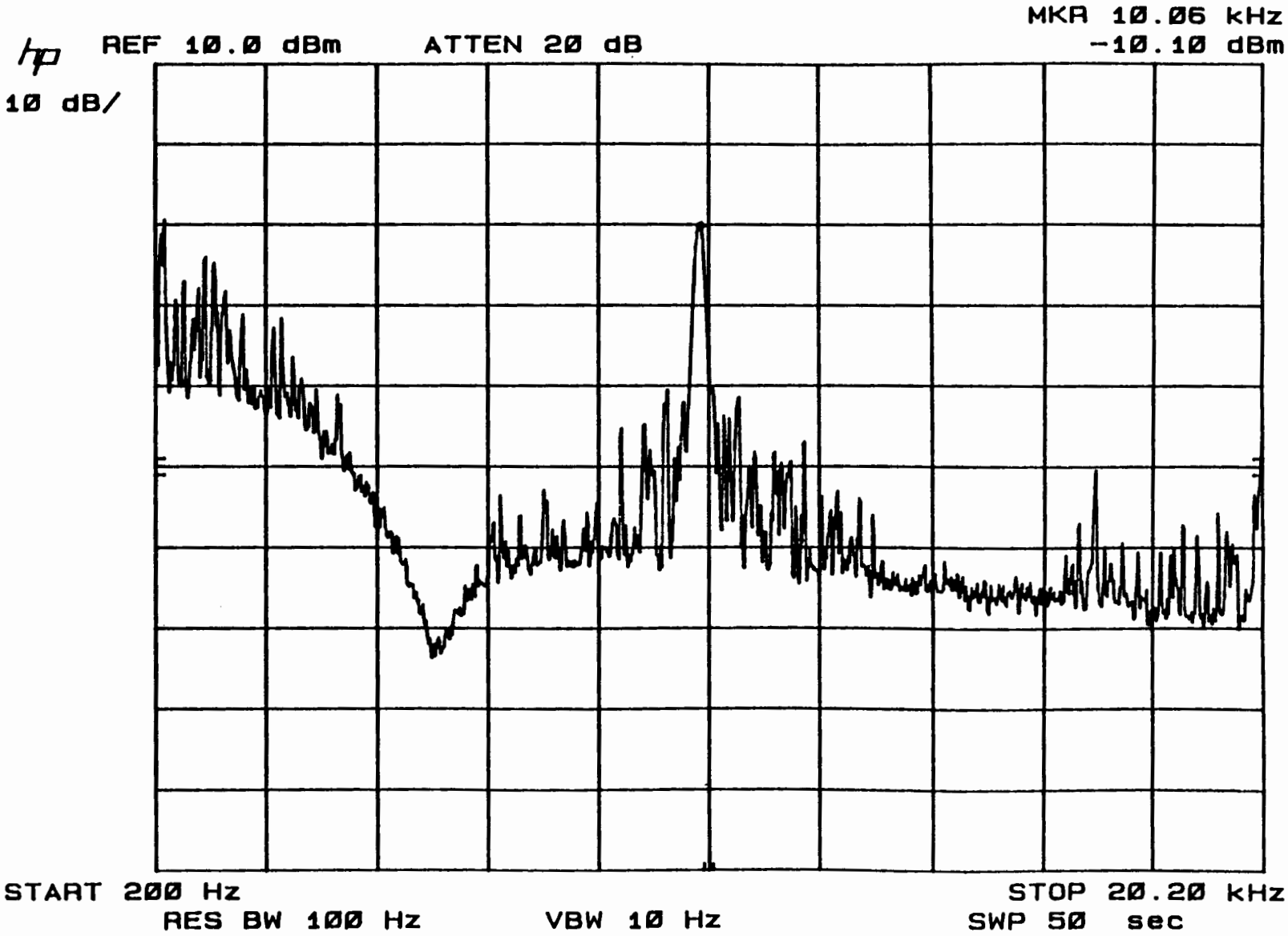

FIGURE 32. RECEIVER 3, +/- 5 kHz, 90-PERCENT VOICE, SIGNAL GENERATOR

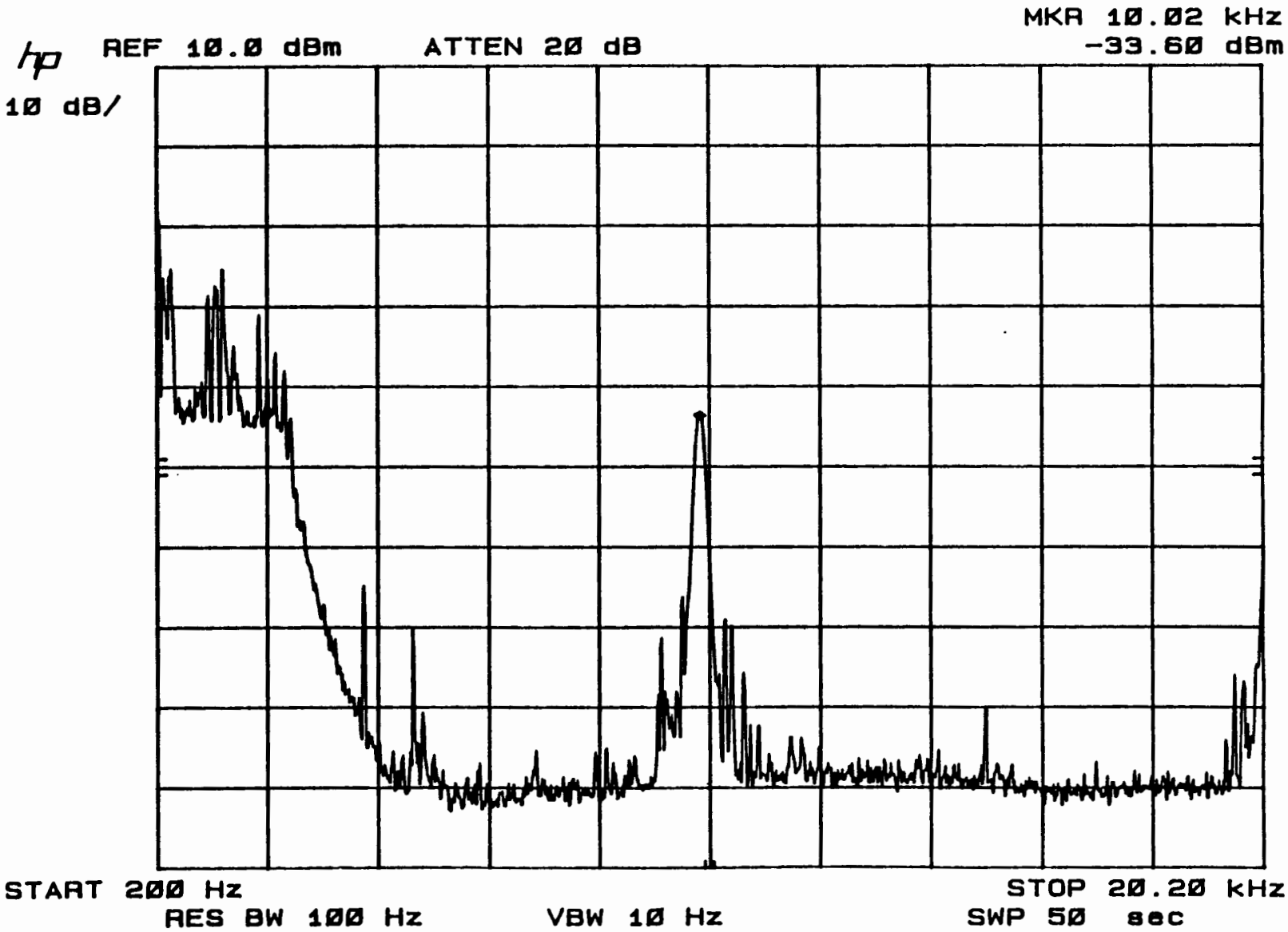

FIGURE 33. RECEIVER 1, +/- 5 kHz, 30-PERCENT VOICE, SIGNAL GENERATOR

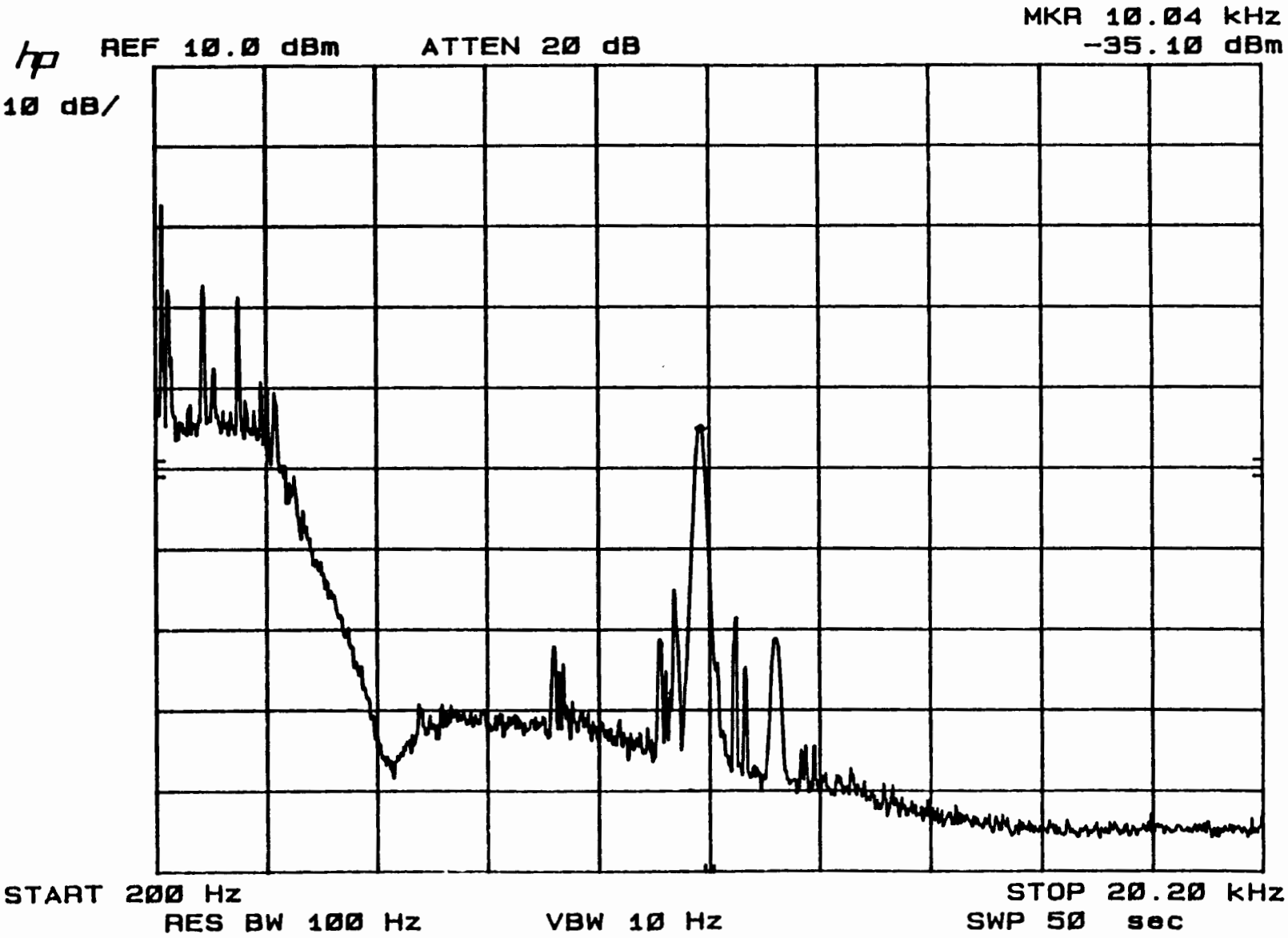

FIGURE 34. RECEIVER 2, +/- 5 kHz, 30-PERCENT VOICE, SIGNAL GENERATOR

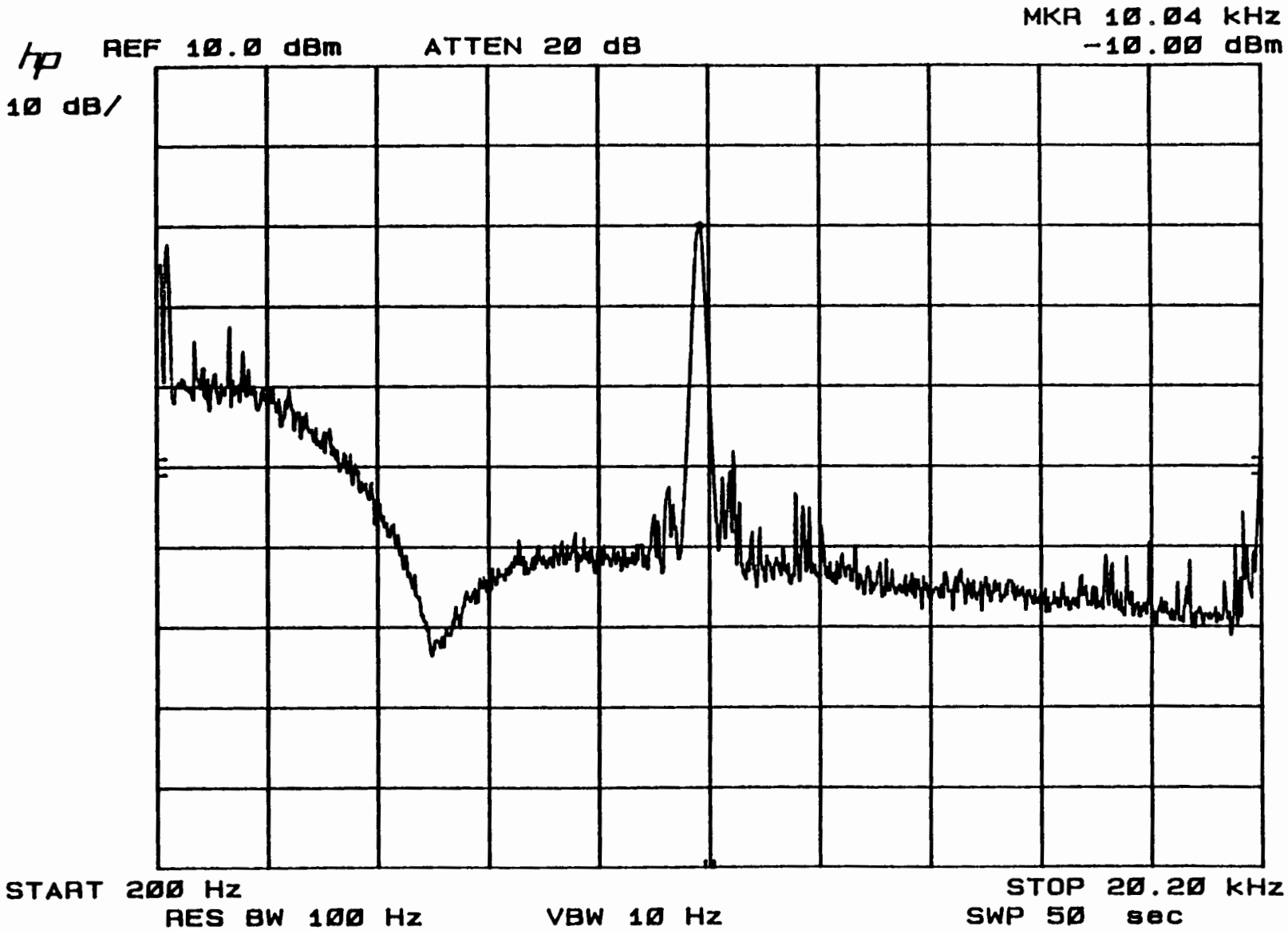

FIGURE 35. RECEIVER 3, +/- 5 kHz, 30-PERCENT VOICE, SIGNAL GENERATOR