22. Standard measurements: Electric fields due to high voltage equipment

by Ralf Müller and Hans-Joachim Förster

The standards for personal safety in electric and magnetic fields have been tightened. Three-dimensional measurement of the fields and the combination of these components into the equivalent field strength is now required. Is this extra effort justified? As part of a study project at the Fachhochschule Reutlingen, high voltage lines, transformer stations and the working environment were investigated. The results show that three-dimensional measurement is indeed necessary.

Measurement methods

An E field sensor basically consists of a pair of condenser plates placed side by side, across which the dielectric current is measured. The disadvantage of this simple arrangement is its directional characteristic. To measure accurately, the direction of the field lines has to be known and the sensor positioned accordingly. This is seldom possible in practice. As a result, the trade association [1] require the measurement to be made in each of the three orthogonal spatial axes and the so-called equivalent field strength calculated by summing the squares of the three field components. This is theoretically possible with a simple probe by making three consecutive measurements in the three directions, assuming that the field remains constant over time. The practical answer is to use a sensor that has a three dimensional structure. Modern measuring equipment uses sensors made up from three plate condensers arranged at right angles to each other, and calculate the equivalent field strength automatically.
The isotropy, i.e. the actual non-directionality of the sensor, is important in this context. This can be assessed by rotating the sensor in an homogeneous field; the indicated field strength must remain constant [3]. This is the only way to ensure that dangerous field strengths are not present.

Measurement conditions

Several factors must be observed if measurements are to conform to relevant standards [1]:

- No person should be present in the immediate vicinity of the measurement.
- Objects in the vicinity that distort the field, such as trees, bushes, machinery, etc., must be noted.
- Environmental effects such as air humidity, temperature, type of terrain, etc., must also be noted.
- No condensation may be present on the sensor or its supporting tripod as this will lead to measurement errors.
- The person operating the measuring instrument must ensure that they do not stand between the field source and the probe during the measurement.

These measures are required in order that comparable and reproducible results can be obtained under varying operating conditions.

Simplest case: The high voltage line

Our first example is a high voltage line running across open land. If the field is measured at the lowest point of the cable sag, i.e. as far as possible from the masts, it can even be assumed that the field lines are vertical. As expected, the measurement results of a three dimensional (isotropic) and a one dimensional (so-called y only measurement) differ only slightly from one another. The maximum difference is below 5%. The slight unsymmetry in the measurement curve is due to the terrain which showed a slight upward slope from left to right. The phase relationships between the conductors are of no consequence in this case as the measurement distance from the conducting cables is too large.

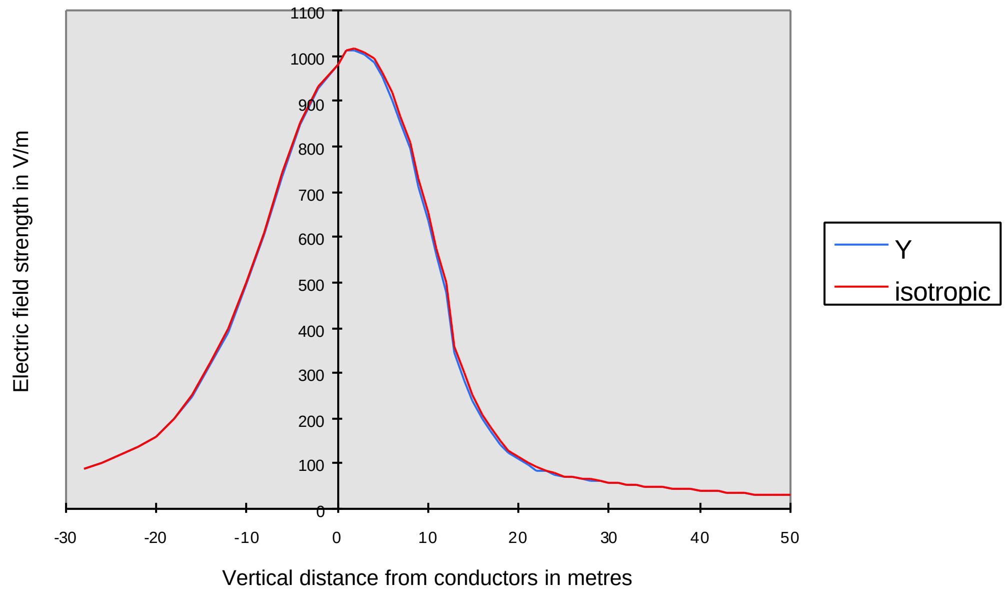

Figure 1: *High-voltage line. Results of electric field measurements in one and three dimensions.*

More interesting: Line crossing

The second example shows the field profile in the area where two lines cross. The measurement conditions were:

- Voltages 110 kV and 220 kV
- Three-phase conductors
- Line 1 (top to bottom): 220 kV, christmastree masts approx. 40 m high
- Line 2 (left to right): 110 kV single layer masts approx. 26 m high

The ambient conditions at the time of the measurement were:
Temperature 16 °C, average air humidity, very damp ground.

Figure 2 shows the basic measurement path. Some trees and a number of small bushes were located in the immediate vicinity of the measurement. The distorting effects of these objects on the field profile are discussed in the evaluation.

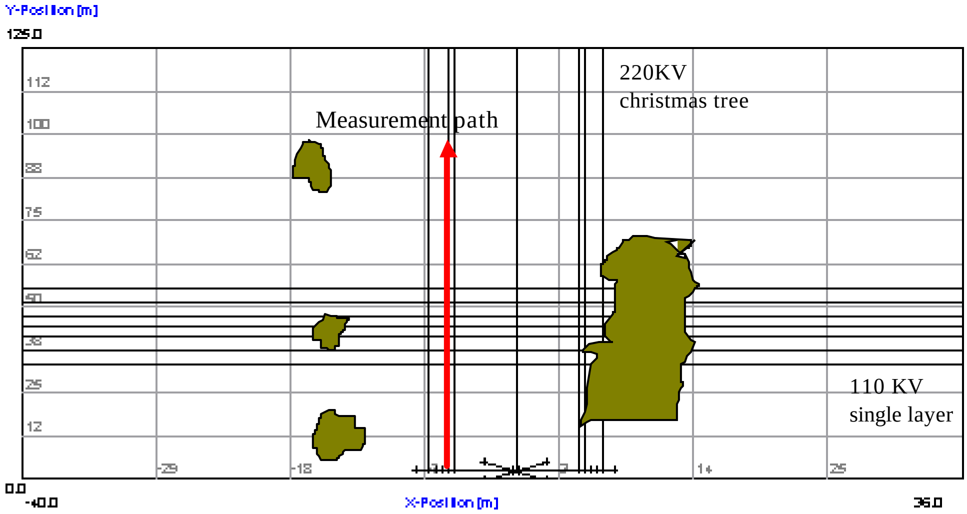

Figure 2: *Measurement path beneath two high voltage lines that cross. Green areas indicate bushes and trees.*

Figure 3 shows the field strength profile that was measured. The starting point of the measurement in the diagram is at the position of the mast. The last measurement was made at a distance of 60 m from this point. The effect of the mast can be clearly seen up to the area where the lines cross. The crossing begins 30 m from the starting point. A field strength maximum occurs at the 28 m point. This is due to the addition of the field strengths of the two lines. In the area of the crossing, the field components of the upper line are compensated, resulting in a minimum at this point. The field strength increases again rapidly after the crossing area, at 52 m. This is due to the fact that the screening effect of the mast is now reduced and the area of the crossing has been left.

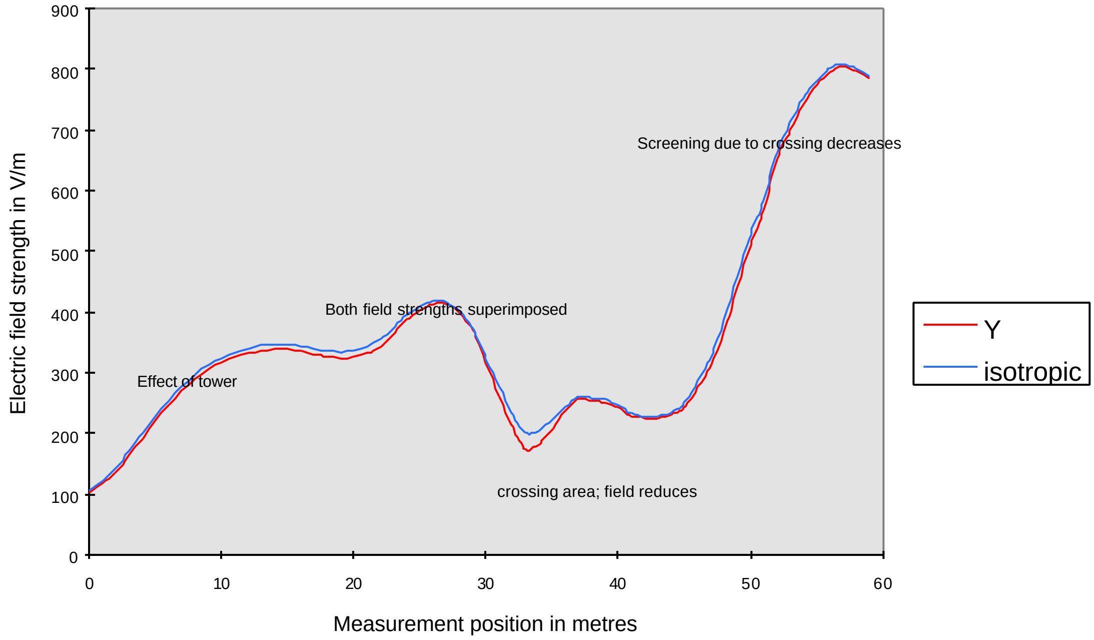

Figure 3: *Electric field profile where two high voltage lines cross.*

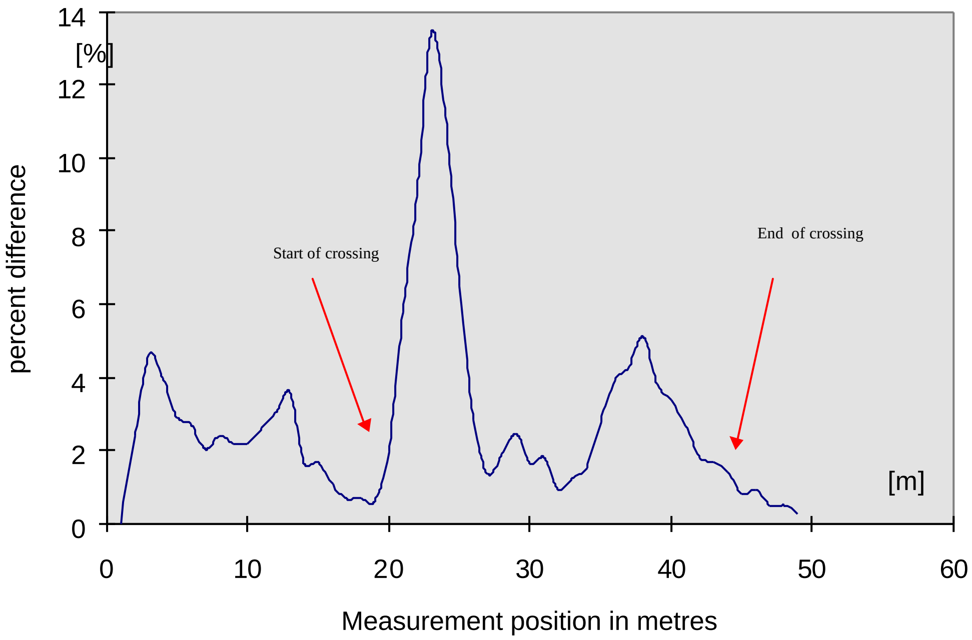

Figure 4: *Relative difference between one-dimensional and three-dimensional measurements.*

Figure 4 shows the relative difference between the one-dimensional and three-dimensional measurements. The maxima are found at the entry and exit of the crossing. The difference is up to 13 %. The lower conductors in the crossing area compensate out the field components of the upper conductors. The variation in the field within the area of the crossing in figure 3 is due to the uneven terrain. This section is therefore shown in more detail in figure 5.

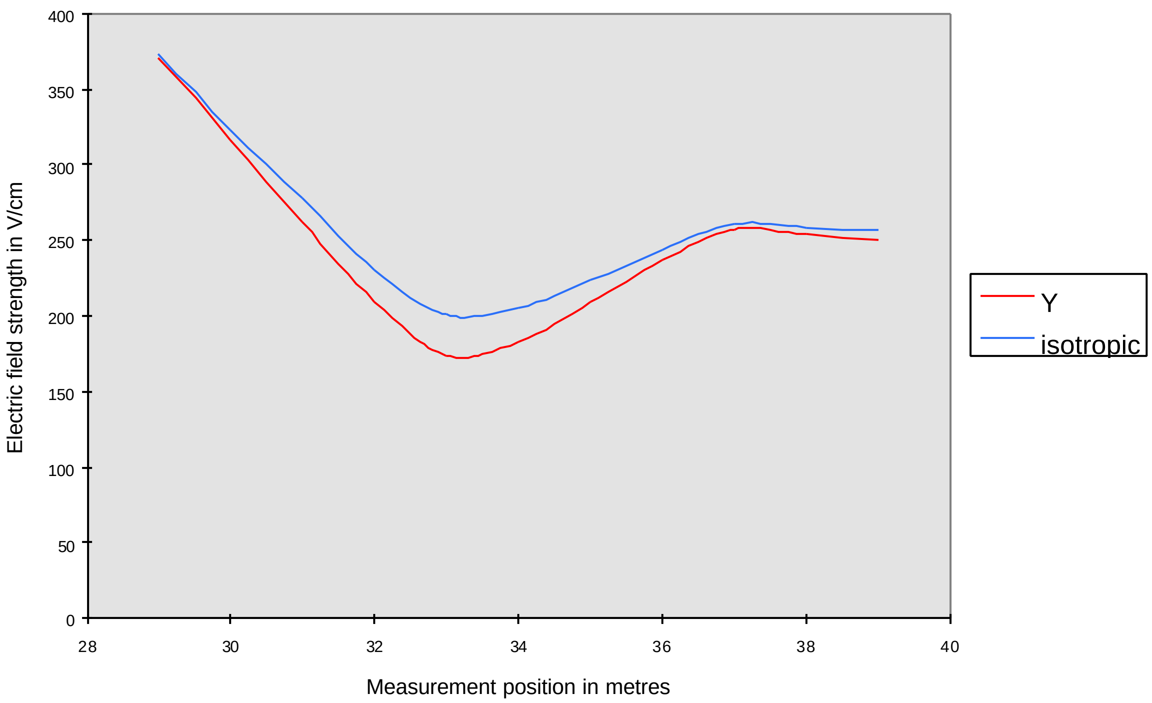

Figure 5: *Zoomed representation of the crossing area from figure 3.*

Figure 5 clearly shows the effect of the terrain on the measurement result. A three-dimensional measurement is clearly to be preferred where the terrain is very uneven. Accurate results are not given by a one-dimensional measurement or by a computer simulation.

Complex: Transformer station

The Neckarwerke Esslingen AG kindly allowed us to make measurements in a transformer station. A measurement path was selected that included several conductor arrangements, insulators and carriers. It is depicted in figure 6.

View from above: **View from side:**

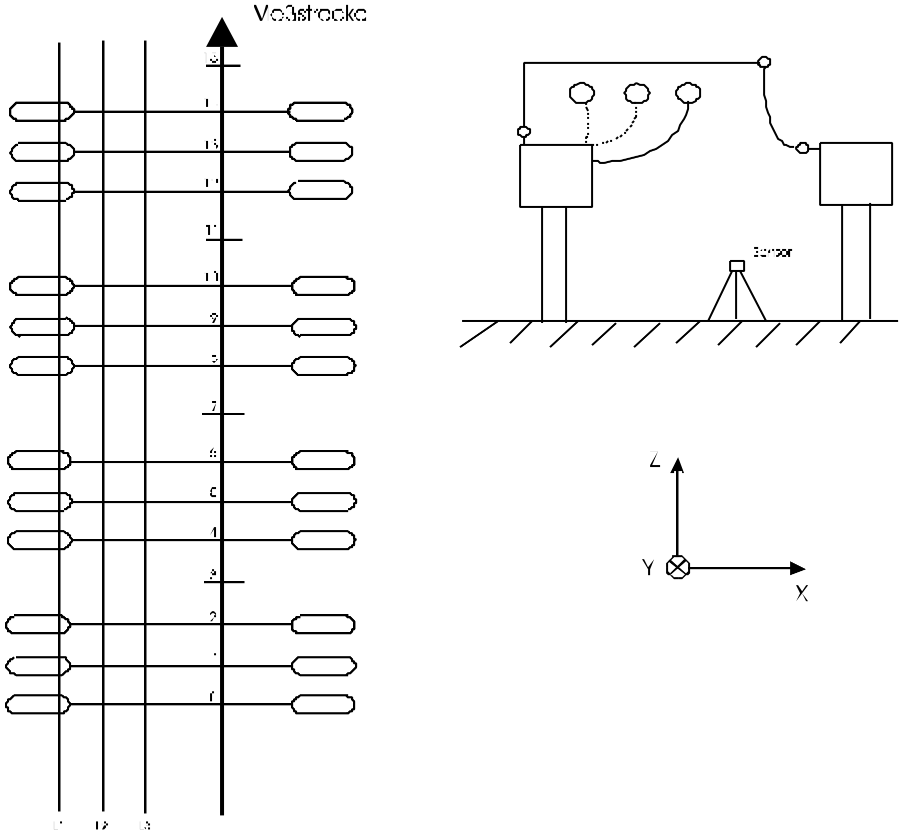

Figure 6: *Measurement path in a transformer station*

The ambient conditions at the time of the measurement were: Temperature 5 °C, average air humidity, very damp ground.

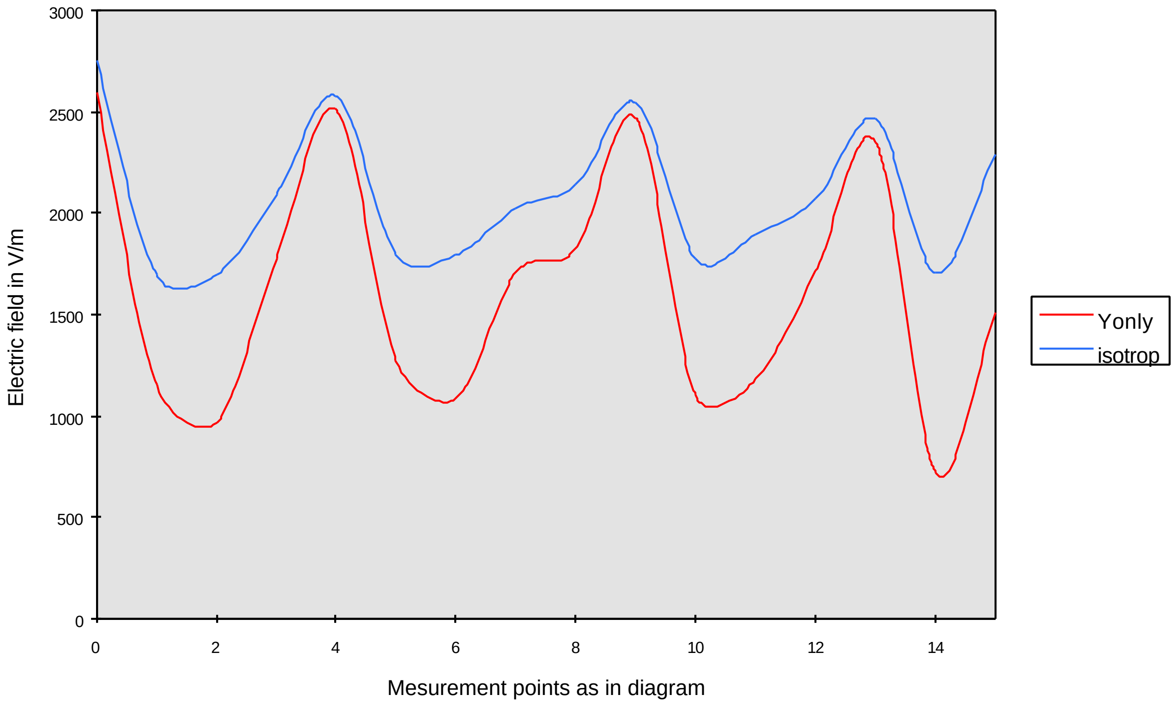

Figure 7: *Direct comparison of one-dimensional and three-dimensional measurement results.*

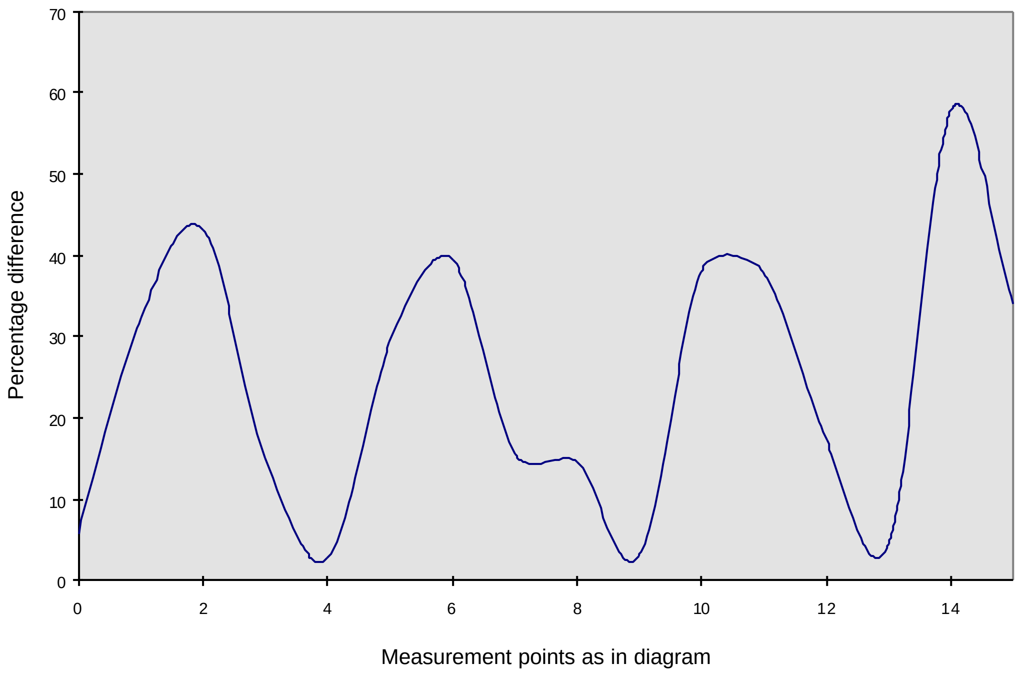

Figure 8: *Relative error between one-dimensional and three-dimensional measurements.*

The measurement results clearly show that significant differences in the results of one-dimensional and three-dimensional measurements occur in the vicinity of crossing conductors, switching equipment, current busbars and the like. The relative error is very dependent on the measurement position. Directly beneath the conductors, it is small, but it can be as much as 60 % at points between the conductors. This difference cannot be accepted when measurements are made for personal safety, especially where legal settlements are involved. The difference clearly shows that the indicated field strength is lower than the actual field strength and hence the assumed safety is not given. This exposes a weakness in IEC standard 833 [4] which exclusively defines measurement in the vicinity of high voltage lines and is therefore not applicable in cases where labor laws are involved.

Unclear: Most working environments

The conditions of most working environments in industry are far removed from the simple case of a high voltage line; switching equipment, transformer stations, induction heaters and machinery may all play a part in the field profile. It is thus not possible to predict the spatial field profile or its variation with time. Further uncertainty results from the frequency spectrum. Several standards specify different limit values for different frequencies. Broadband measurement equipment cannot therefore be used if the frequency of the field is unknown or if several fields are superimposed. As an example of this, an induction heater emits radiation at the a.c. line frequency of 50 or 60 Hz and its harmonics and also at the frequency of the heating current. The latest test equipment copes with this situation by employing built-in filters to detect the main radiation components and evaluate their frequencies. The use of three dimensional measurement techniques coupled with filters is an absolute must if personal safety measurements are to be made that are reproducible and which conform to the relevant standards.

Bibliography

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[2] Electric and Magnetic Fields
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Field probes for calibration and for determining the magnitude and direction of electric field strength (in German)

[4] International Standard IEC 833: Measurement of power frequency electric fields

[5] German Standard VDE 0848 Part 1: Endangerment due to electromagnetic fields. Measurement and calculation methods (in German)

[6] German Standard VDE 0848 Part 4: Safety in electromagnetic fields. Field strength limit values for personal safety in the frequency range from 0 Hz to 30 kHz.

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