

ENGINEERING PRECAUTIONS IN RADIO INSTALLATIONS*

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Probably all devices used to produce some desirable result may, under certain conditions, produce or contribute to the production of undesirable results, or damage. The probability of damage from radio apparatus compares favorably with that from other useful devices, and is apparently decreasing. However, radio apparatus may produce damage, and a discussion of the matter may result in future prevention of damage.

In this paper the subject will be considered under four general headings.

1. Wherein dangerous shocks may be received from radio apparatus.
2. Wherein radio apparatus provides a path for currents other than radio currents.
 - (a) Lightning.
 - (b) Antennas coming into contact with lighting or power lines.
3. Wherein radio apparatus provides the current or potential by direct discharge.
4. Wherein radio apparatus provides the current or potential by induction.

1. Injurious shocks may be received from the transmitter circuits used in very high power stations or in lower power stations should the operator come in contact with the power transformer secondary when the transformer is disconnected from the radio circuits. Radio frequency currents are usually, at worst, only disagreeable.

There are, or were, a few cases of dangerous practice along these lines. One was to shunt the operating key, so that the transformer secondary was at a fairly high potential when the key was open. Another dangerous method and probably by

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far the most dangerous to the life of the operator, was to use alternating current primary generators which gave an open circuit voltage as high as 500 or 600 volts and connecting that high voltage circuit thru the operating key.

Possibly it is reasonably safe to use a generator open circuit voltage as high as 250 but, all things considered, it may be best to bring this voltage down nearer 110, even if efficiency of transformation has to be sacrificed slightly.

2 (a). The danger of fire being produced by lightning striking the antenna is apparently less than the danger in ways mentioned under headings 2 (b), 3, and 4. Personally, I have never seen lightning strike an antenna, nor have I seen evidence that lightning has struck an antenna. However, I have frequently seen antennas discharge to ground when lightning apparently struck at some distant point. For example, in one case, using an antenna 200 feet (60 meters) high, the discharge jumped a gap of 3.5 inches (8.7 cm.) to the ground. On several occasions, in mountainous districts, I have seen lightning striking apparently on all sides of a radio station. On one such occasion, lightning struck a one-story house about six blocks from an antenna 200 feet (60 meters) high. On another such occasion, lightning apparently struck a high tension line near the radio station, judging from the crash which was apparently coincident with the flash and from the fact that the high tension transformer in the sub-station within a couple of hundred feet was burned out.

2 (b). At one time a report was brought in that lightning had struck a radio station burning up the receiving apparatus. On investigation it was found that someone had changed the antenna wires from their former position and had placed them across and above a 1,200 volt line. When the ropes supporting the antenna stretched, the antenna dropped down on the 1,200 volt line and grounded this line thru the receiving apparatus, burning up the receiving apparatus. On other occasions, antenna wires have dropped across telephone lines, and lighting and power circuits. In the case of the telephone lines, the radio transmitters discharged to the telephone line, usually short-circuiting the telephone lightning arresters; while in the case of the lighting and power circuits, the power circuits usually were short circuited, burning out fuses. However, in those cases, had the receiving instrument been connected, it is possible that the power circuits might have discharged thru the receiving instruments and burned them.

In cities, where lighting, power and telephone circuits are exposed, trouble may arise from antennas dropping across such wires, and in the larger cities where fire alarm circuits and telephone circuits frequently run across the roofs of houses, these circuits may be frequently damaged by antenna wires dropping across them and by their receiving direct discharges from the transmitters.

The greatest number of fires I have noticed starting from direct discharge of transmitters have been where roof insulators or deck insulators leaked current to the roof or deck, and where the roof or deck was of some combustible material. However, none of these fires have resulted in serious conflagrations, probably because they almost invariably occurred during rain or very damp weather, the dampness or rain serving both to short-circuit the insulator and put out the fire.

Portions of transmitters, such as condenser supports, transformer supports, etc., have frequently been charred to some extent. There is less danger of fire being caused by the apparatus which is mainly in use now because, with the exception of auxiliary apparatus as used by one company but now being discontinued, the plain antenna method of connection of the transmitter has been discontinued. This plain antenna connection brings the full spark gap potential to the roof or deck insulator, thereby causing it to break down. A majority of the cases observed where the roof or deck was set on fire were brought about by this type of apparatus.

For the benefit of persons who have not given thought to the subject of insulating radio transmitters, a few points concerning insulation may be proper. These points refer mainly to the transmitter and include the antenna.

A. Air is a good insulator. Its insulating qualities are least liable to be affected by dust, moisture, or age; also, it is cheap. That is, it is desirable to use plenty of air space, when practicable, between points where a discharge might take place.

B. Long and narrow surface insulation is desirable, much on the same principle that a long, narrow conductor has a higher resistance than a short, thick one.

C. Insulators having corrugated surfaces, or surfaces which furnish tortuous paths, are desirable, as such insulators require radio frequency currents to travel over long paths. For the same reasons, such insulators are desirable for direct current and audio frequency potentials.

D. Non-combustible, non-absorbent materials (for example,

porcelain) are preferable for insulators where it is possible to use them.

E. Insulator surfaces should be kept clean and dry.

In the earlier days of radio work, a common method of bringing the antenna thru the wall of the house was to bring this connection thru the middle of a large window pane. This practice was usually fairly satisfactory and not very expensive.

For inside work, the writer adopted a general rule of providing surface insulation equal to eight times the sparking distance thru air. For example, if the wire used in the circuit would spark to objects at a distance of one inch (2.5 cm.) thru air, this wire was held away by a porcelain rod one inch (2.5 cm.) in diameter and eight inches (20. cm.) long.

Porcelain cleats in series are probably as inexpensive an insulator as may be used for guying small antennas, considering their insulating qualities.

4. For the purpose of this paper, the currents which are set up in conductors not connected to antenna, but due to the radio frequency currents in that antenna, will be referred to as "induced radio currents", and the transference of energy from the antenna to other unconnected circuits will be referred to as "by radio induction".

The greatest damages from fire which is known to me have occurred where the transmitters were not connected with the point which took fire. In these cases the transmitter caused high potentials in conductors which were more or less distant from the transmitter; that is, these conductors acted somewhat as receiving antennas, and were close enough to rise to a high potential. Where these conductors consisted of telephone circuits the lightning arresters provided on the telephone circuits usually short circuited to ground by the fusing of the metal in the arrester.

This grounding of the telephone circuits usually rendered the telephone circuit inoperative. In the cases of lighting and power circuits carrying direct current or alternating current, such as 60 cycle alternating current, the high potential radio frequency alternating current induced on these lines was apparently superimposed on the direct current or audio frequency alternating current. The radio frequency current produced on these lines was frequently of very high voltage comparatively while the other current (direct, or audio frequency) on the lines was of comparatively high amperage. When the radio potential occurred at a point within striking distance of an object at op-

posite potential, it apparently discharged and carried the direct current or audio frequency current over after it. In many cases the arcs so formed held until the terminals of the arc or part of the circuit burned away. Power transformers, lighting transformers, motors, generators, relays, magnetos, watt meters, ammeters, volt meters, lamp sockets, rosettes, etc., burned out or were rendered inoperative apparently from this cause. On a number of occasions lamp cord carrying 110 volt direct current, or 60 cycle alternating current, has been short circuited, and on one occasion an 8 foot (2.4 meters) drop cord disappeared in flame and a nearby motor was short circuited. On other occasions, lamp cord lying against wooden moulding short circuited and burned, setting fire to the wooden moulding. On these occasions, people were nearby and put the fire out before it reached any material magnitude.

On one occasion receiving and transmitting apparatus were located very near to the transmitter. The result was that motor and generator windings, relay windings, reactance coil windings, etc., were repeatedly short circuited. This was stopped by providing radio frequency paths thru condensers across points which developed high radio frequency potential; also, by placing the wiring in grounded iron conduit, and the short sections of wiring of the switchboard in grounded lead covered wires; and finally, by placing a grounded wire netting screen between the transmitter and the apparatus. All of these expedients were put into effect before noticeable potentials were avoided.

Radio frequency currents possibly in some cases have been superimposed on high tension circuits of the transformers, at least across portions of the secondary of such transformers. It is not quite so easy to conceive how this radio frequency potential may occur in the secondary where so many turns of fine wire are used.* However, when transformers were placed in certain relation and near radio frequency circuits they broke down sometimes between sections and sometimes from secondary to primary, and similar transformers when substituted and moved further away or turned at an angle did not break down.

In the United States in 1901, in order to prevent induction in mast guys, these guys were made of rope. In 1902, owing to the stretching and contraction of the rope in dry and wet weather, the writer substituted steel guys with rope blocks and falls at

*A probable explanation is the distributed capacity of the secondary windings and consequent internal resonance effects with breakdown.

the bottom of the guys to serve both as insulators and as means for adjusting the guys. About this time, or before, others used wooden strain insulators in the guys. On some occasions both the rope insulators and the wooden strain insulators were burned by current leakage between the guys and ground. Even on shipboard, attempts were made at times to insulate guys and stays between masts. However, owing to the difficulty of providing insulation which would not leak, the principle of thoroly grounding the stays and guys was adopted. Stays and guys and other metallic conductors, such as hand rails, occasionally discharged to passengers, causing considerable excitement and fear on the part of some steamship companies that passengers might be electrocuted. The remedy used for this was thoroly to ground stays and guys, etc. Even the metal whistle cords on vessels occasionally discharged to damp wood work, etc., and often a person who tried to manipulate the whistle received a shock. These were grounded by using flexible wire ground connection. Steel beams, steam pipes, long bolts, anchor chains, and other conducting materials, on vessels, have been known to spark to ground or to other conductors. Conduits containing electrical wiring have apparently discharged to the ends of wiring where the conduits were not grounded. Metal roofs in the vicinity of land stations, and metal roofs of wharves, have discharged to ground, causing charring of the wood to such an extent that fear of fire resulted.

On account of sparking on their vessels, one line had a tendency to accuse the radio apparatus of being responsible for nearly anything that went wrong with the electrical circuits on the vessel, even going so far as to say that the radio currents went down thru the vessel and into the water condenser of the engine and caused electrolysis to such an extent that the water condenser had to be replaced!

On a line where the vessels were almost entirely constructed of wood, sparking, charring, and injured apparatus resulted at a number of points. The mast stays were wrapped with houslin and passed thru thimbles connected to the hull of the vessel, thereby insulating the mast stay from the hull of the vessel by the houslin. This houslin was set on fire and burned away, due to the sparking between the mast stays and the hull of the vessel via the thimble. On these vessels the mast head lights, running lights, and port and starboard lights, were connected to the pilot house signal light switch board by means of rubber covered twin conductors without metal covering. All of these signal light

circuits were burned out from time to time due to sparking across the lines or between the lines and ground. Annunciator circuits and call bell circuits thruout the vessels discharged to metal portions of the ship, and in some cases caused slight charring of woodwork.

On one occasion a steamship company asked that their vessel be gone over with a view to preventing any possibility of igniting explosives which they expected to carry. In this case it was recommended that all metallic conductors in the hold and in the vicinity of the hold be thoroly grounded and electrically connected together, even the short metal ladders and supports which extended from one deck to another.

Three instances are recalled of wooden masts set on fire due to the discharging of guys to each other thru the woodwork of the mast. In two of the cases the masts were burned off several feet from the top. In these cases the guys were 50 feet (15 meters) or more from the antennas.

It has been found that radio currents were induced in the metallic paint on masts and on some occasions the metal paint was removed and a portion of the mast varnished. Some years ago it was the rule to make all radio masts of wood. Also wooden top masts have been required on shipboard because of the radio apparatus.

Regarding the ability of sparks to start fire, that obviously depends on the heat developed by the spark and the heat required by the combustible material. Very small sparks are almost universally used for igniting gas or gasolene vapor in gas engines, and it is quite possible that similar gas might be ignited by equally small or smaller sparks on shipboard or at other points near radio stations. Sparks developed by radio transmitters might be capable of igniting oils such as are found, for example, in the paint lockers on vessels. Theoretically, radio might cause distress conditions by setting the ship on fire and then relieve these conditions by bringing aid!

While the paper has been confined practically entirely to personal observations, the conclusion is not to be drawn that the damaging results always occur. The instances mentioned practically cover all the cases noted during a period of about 15 years use of radio frequency circuits, including radio frequency apparatus operated under a large variety of relations to adjacent conductors at stations on both coasts of the United States, at numerous points inland, and on the vessels of several nations.

Protection against radio frequency currents of dangerous potential being induced in low potential direct current of audio frequency circuits may be brought about to a considerable extent by taking advantage of the ways in which radio frequency currents differ from direct current and audio frequency currents.

Condensers of small capacity impede radio frequency currents very much less than audio frequency currents; (that is, radio frequency currents usually find an easy path thru small condensers, while practically no 60 cycle current or direct current will flow thru small condensers.) For practical purposes small condensers may be assumed to be good conductors for radio frequency currents and insulators for direct current and alternating current having frequencies in the neighborhood of 30 to 500 cycles.

Condensers have been installed in series with fuses to ground. This practice is objectionable because if the fuses burn out, the lines are left unprotected at a time when such protection is most likely to be needed, and unless the fuses are in some way arranged to notify some person, it is quite probable that they will not be known to have burned out until after damage occurs to the low tension circuits.

Mica condensers in which lead foil was used have been found to provide automatic self fusing devices without destroying the service ability of the condenser; for example, when a sheet of mica punctured making a small hole, the lead foil melted away from around the hole until the arc was extinguished and the condenser then operated as before.

Radio frequency currents do not penetrate very far into the conductor, or flow to any great extent in a conductor when that conductor is screened by a concentric conductor such that the radio frequency may flow in the concentric conductor; thus, for example, very little if any radio frequency current will be induced in a pair of rubber covered copper wires enclosed in an iron conduit, where the iron conduit is grounded at intervals.

Low potential circuits have often been protected from radio frequency potentials by grounding the low potential circuits thru high resistance rods made up of carbon and clay; and in some cases by using incandescent lamps between the conductors and ground. The writer has always considered this an objectionable practice, because to some extent it grounds the low potential circuits, which are usually better ungrounded. Also, according to the experience of the writer, these high resistance grounds have apparently offered, as a rule, greater impedance

to the radio frequency currents than small condensers offered. Slate switchboards sometimes served as protectors to low frequency circuits because their resistance was sufficiently low to allow them to act much as the high resistance protective rods.

Less trouble has occurred since more metal has been used in the construction of ships, in the form of bulkheads, decks, and supports. In addition, the doing away with wiring in wooden moulding and the substitution of metal moulding, conduit, and metal covered cable has prevented radio frequency currents from being produced in the direct current and audio frequency wiring. Lead covered wire has been used sometimes, but has occasionally caused trouble when the lead has been mechanically forced thru the insulation and against the copper. It is probably preferable to use lead covered wire in protecting metal conduit with drains in the lower portions of the conduit to take care of sweating, etc.

Besides preventing sparking, another reason for thoroly grounding the stays and mast guys on vessels was the assumption that less energy is absorbed from the radio waves by thoroly grounding these stays than that which would probably be consumed in the resistance over leaking insulators.

The increasing knowledge and improving practice of professional radio engineers decreases the probability of damage. However, inexperienced persons instal transmitting and receiving stations from time to time, using such various types of apparatus as their circumstances and knowledge provide. Such stations as these are frequently erected in private houses, where sparks may occur on combustible material, and where telephone and lighting wires may not be protected by conduit or grounded metal covered wire, and where the antennas may be above or may parallel nearby telephone, fire alarm, lighting, and power wires. It might be useful to offer a set of rules to cover the various possibilities, but that would require very careful study, if these rules were drafted, to prevent imposing hardship on the young experimenter and radio student, who generally is limited as to means.

Rules might be prepared by a Joint Committee of the American Institute of Electrical Engineers and The Institute of Radio Engineers. These would make a useful addition to the Underwriters' Rules and improve engineering practice.

The radio laws which require low decrement and practically single waves to be radiated from transmitters, made for the purpose of preventing interference, may serve as a protection against radio transmitters causing damage. These laws, with

their resulting regulations, aid in eliminating the plain aerial type of transmitter whereby the antenna was raised to excessively high potentials, and because of the lower decrement, nearby circuits, unless their natural period is somewhat near that of the radio frequency, may not be excited to such an extent. High group frequency transmitters and especially transmitters of constant amplitude waves use lower voltage for equal power, which results in lower voltages being induced in nearby conductors. These types of transmitters are coming into general use and the constant amplitude wave transmitters may be the transmitters of the future. Therefore, the probability of damage should continue to decrease.

When the current flows in an antenna, magnetic and electrostatic fields are produced around that antenna; therefore all conducting materials in these fields are conductors in the dielectric of a condenser, and at the same time they are conductors which cut a magnetic field. Considering the antenna as one plate and the earth as the other plate, and the air between all parts of the antenna and the earth as the dielectric, all conductors within this air space will be at a different potential from both the antenna and the earth, while this condenser is being charged. As the antenna may be periodically charged to a high potential, the conductors in the dielectric may be periodically at a high potential with respect to earth, depending on their distance from the earth and from the antenna. If these conductors are at any time raised to a potential sufficiently high to break down the solid or air insulation between them and earth, they will discharge or spark to earth. Now, if these conductors are carrying another current such as direct current with a direct current potential difference to ground, then the direct current will as a rule, it may possibly be said, follow the spark, and establish an arc which may hold until the circuit is opened by some portion burning away whether that portion be a fuse, a wire line, or generator winding. In the same manner both terminal wires of a motor or generator may spark simultaneously to the armature core, and produce a short circuit. This may occur whether or not the motor or generator is grounded because the motor or generator usually occupies a relatively different position in the dielectric from that occupied by the line wires.

Where conductors are within sparking distance of the antenna a discharge may take place, altho the conductors may be insulated from ground and from the antenna, and this for the same reason that such conductors discharge to ground. For example,

antenna circuits frequently discharge to such small masses of metal as wood screws, altho the surrounding wood is a good insulator.

Conductors are usually so placed as to cut the magnetic lines emanating from the antenna or the closed circuit of the transmitter; and a potential difference between the ends or portions of a system of such conductors may result which will break down the insulation. If these ends or portions are, for example, the opposite terminals of a motor or generator, or the terminals of a magnet, a short circuit may result. The electrostatic and magnetic fields may work together to produce such damage.

The shorter waves formerly used may have corresponded more nearly to the natural wave lengths of conductors which were found on shipboard in the lower potential circuits than do the longer waves used at present. When the conductor which tends to spark to ground or to the frame of a dynamo is connected to ground or to the frame thru a condenser, and where that condenser is relatively of much higher capacity than the capacity of a conductor to ground or to the object to which it tends to spark, the effect is probably somewhat similar to bringing the conductor quite near to the ground or the frame, and the nearer the conductor is to ground or to the frame, the lower the potential difference that exists between the conductor and ground or frame. That is, the conductor will be brought to a point of lower potential in the potential gradient between the antenna and ground. Or this protective condenser may be possibly regarded with fair correctness as a very low impedance so far as the radio frequency potential is concerned; and where a relatively low impedance is in circuit, the potential across that impedance must be relatively low. In other words, a relatively low impedance is provided for the radio frequency current around the insulation provided for the direct or audio frequency current.

Test made at the United Wireless Telegraph Company's Manhattan Beach station on Aug. 21, 1909, are interesting in these connections.

Referring to the Figure:

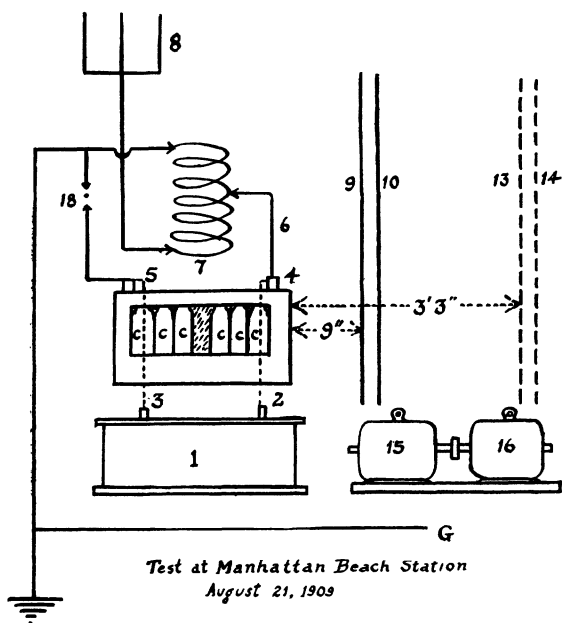
1, 2, 3, 4, 5, 6, 7, 8, 18, 19 represent the United Wireless transmitter.

1. 2 K. W. 60 cycles transformer.

2, 3, 4, 5. Connections between transformer secondary and condenser.

6. Connection to coupler.
7. Helical coupler (oscillation transformer).
8. Antenna.
18. Spark gap.
19. Ground.
- c-c* Condenser (Leyden jars).

9, 10, 13, 14 represent the relative position of two test wires each of number 10 B. & S. rubber covered copper wire* 5 feet (1.5 m.) in length. The wires were parallel and 3 inches (7.62 cm.) apart. These wires were open and insulated, and their lower ends were either brought near together or near to the earth or motor generator, so as to ascertain over what length of gap they would discharge.



15-16 represents a 2 K. W. Holtzer Cabot motor generator, on an iron base, insulated from ground. Motor (15), Generator (16). The motor generator was disconnected, power for the transmitter being taken from the city mains.

G. Wire connected to copper plate in earth, approximately 15 feet (5 m.) long.

*Diameter of number 10 wire = 0.102 inch = 0.259 cm.

The transmitter operated at full power, and radiated two waves (at 500 and 960 meters).

a. Test conductors at 9 and 10. No noticeable discharge between two lower ends.

b. Same at 13 and 14.

c. 9 or 10 discharges over 0.25 inch (0.6 cm.) air gap to ground (*G*).

d. 13 or 14 discharges over 0.17 inch (0.4 cm.) air gap to *G*.

e. 9 or 10 discharges over 0.06 inch (0.15 cm.) gap to motor generator (insulated from ground).

f. 13 or 14 discharges over 0.03 inch (0.08 cm.) gap to motor generator (insulated from ground).

g. 9 in grounded Greenfield conduit discharges approximately 0.01 inch (0.025 cm.) to ground (*G*).

h. 9 in ungrounded Greenfield discharges 0.22 inch (0.55 cm.) to *G*.

i. 9 in grounded Greenfield discharges 0.14 inch (0.35 cm.) to ungrounded motor generator.

j. 9 in Greenfield connected to motor generator, discharges less than 0.01 inch (0.025 cm.), to motor generator.

k. 9 in Greenfield connected to motor generator shows no discharge to motor windings.

l. 9 in grounded Greenfield discharges 0.14 inch (0.35 cm.) to motor windings.

m. 9 connected thru 0.013 μ f. condenser to motor generator shows no discharge to either motor generator frame or motor windings.

n. Motor generator discharges 0.22 inch (0.55 cm.) to ground (*G*) when 9 is connected to motor generator thru 0.013 μ f.

o. Motor generator shows no discharge to ground when connected to ground thru 0.015 μ f. (conductor 9 was connected to motor generator thru 0.013 μ f.).

Considering the antenna and earth together with the intervening air as a condenser, if we wish to protect conductors in this air dielectric against discharges from one plate or the other of this condenser, we must do one of two things: Either thoroly insulate the conductors to be protected or connect them electrically to the plate to which they have a tendency to discharge. That is, they must be thoroly insulated or made part of one plate or the other. As the insulation between low voltage circuits and ground is as a rule only sufficient to insulate the normal potential on the low voltage circuits, it is necessary to provide means for connecting these circuits to ground so far as radio

frequency currents are concerned, or to enclose them within the ground plate of the condenser rather than in dielectric.

The case is one of conductors subjected to alternating stress in the dielectric of a condenser and at the same time to an alternating magnetic field.

The problem is to prevent these conductors from sparking. The usual solution is to ground thoroly all conductors which are not there for the purpose of carrying current, and to enclose current carrying conductors in grounded metal coverings (e. g. metal conduit). Where this is not practicable, it is desirable to connect the current-carrying conductors to ground and to each other thru condensers (e. g. lead foil and mica condensers of approximately 0.17 μ f. capacity tested at 500 volts, 60 cycle alternating current and enclosed in copper water-tight cases). In building a radio station, it is desirable to place all current-carrying conductors (other than radio) underground so far as practicable (and especially telephone conductors). The first continuous grounded metal deck of a vessel, below the radio transmitter, may be usually considered as the surface of the ground in so far as this protective effect is concerned.

SUMMARY: Various types of possible danger from radio installations are considered: shocks to the operator, short-circuit from lightning or from contact with high tension power lines, breakdown from the high tension circuits of the radio transmitter itself, and harmful inductive effects from radio transmitters.

In each case, instances are given together with the proper means of avoiding the undesired effect. In this connection, some detailed experiments are described.