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THE TWINTRON
A NEW ELECTRO-MECHANICAL TUNABLE RESONATOR

by

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and

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THE TWINTRON

A New Electro-Mechanical Tunable Resonator

by

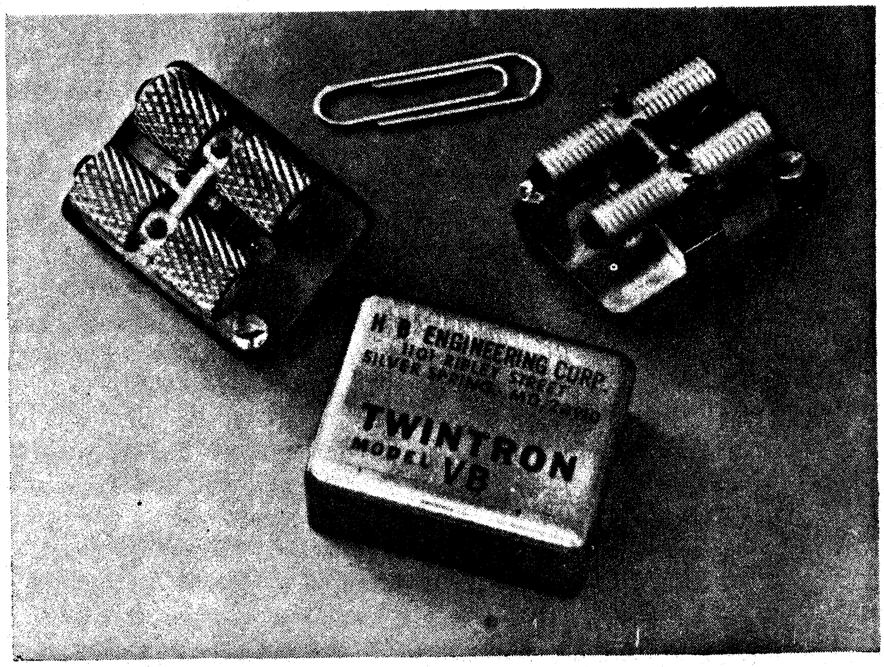
Hugh Baker and John Cressey

It is around this paper that the authors talked about the TWINTRON at the October 12, 1967 meeting of The Radio Club of America. Both are with HB Engineering Corporation at Silver Spring, Maryland.

For many years the electronics engineer has been taking advantage of many forms of mechanical resonators in his dealings with audio and sub-audio frequencies. At these low frequencies, the use of LC or RC frequency networks generally become impractical because of the large time constants involved and the large physical size of the associated L and C components. This condition is particularly true when the frequency selectivity, or Q, of the device must be high. There is an unfavorable mathematical relationship between the increase in the values of L and C in these networks and the resultant increase in Q. When any form of transducer is used with a mechanical resonator, it becomes an electro-mechanical resonator which can be made to filter or generate electrically the frequency at which the mechanical device resonates.

There are three classic mechanical resonator forms in typical use in the audio spectrum. These are the tuning fork, the cantilevered beam and the simply supported beam. Each of them is typically activated electrically through electromagnetic, piezoelectric or magnetostrictive transducers. The mechanical motion, which is at its peak at the resonant frequency of the device, is sensed or picked off by the same type of transducers or through capacitance, photoelectric, or electrostatic coupling devices. The choice of the input and output arrangement is dictated by many factors, including the nature of the mechanical resonator and the characteristics of the input and output circuitry.

In the audio spectrum, many applications have been made practical by these electromechanical resonators. While they solved several problems, they created others in the process. The most typical of the created problems is the susceptability of mechanical resonators to outside mechanical influences, particularly external shock and vibration. While the piano tuner is quite happy with the fact that he can ring his tuning fork with a sharp blow and then amplify its note by placing it against a sounding board, the electrical engineer finds this characteristic devastating when he is designing any type of communication or remote control system using tone signaling. At the remote site in such systems, he is depending on the ability of the remotely actuated circuit to respond only to a single specific tone or frequency, and more importantly, to do so only when the command or transmitting end of his system transmits that particular frequency. If the electromechanical filter at the remotely controlled station goes into motion with the passing of a freight train



or the shake and rattle found in an aircraft or in an industrial environment, the remote circuitry may be triggered into action without regard to the commands of the controlling tone transmitting station.

This problem is compounded if a multitude of closely spaced frequencies or tones is involved in the control system. It is not uncommon to have the mechanical vibration of one electromechanical filter set in motion an adjacent filter even though it has a resonant frequency which is different. In such systems, great care is taken to mechanically isolate one mechanical filter from another and from any shock and vibration which might be present in the chassis or mounting base.

Tone systems used for relatively low speed supervisory control, data communications and a multitude of alarm, monitoring and control systems offer many advantages, particularly in the economic aspects of being able to use a low quality or voice grade communications link between points in the systems. Railroads, pipelines, telephone and teletype links, and many similar extensive networks have historically relied heavily on tone communication. But with the eternal need for more information capacity in such systems, it became necessary to increase the number of data channels these systems can squeeze into the allotted frequency spectrum.

The demand for more information reached a point where tone systems became less and less practical for such requirements since the cost of the high Q and highly stable tone generators and filters pushed the system cost up so high that microwave links and other telemetry techniques became more appropriate. There was an obvious need for a new form of electromechanical resonator which could offer the selectivity and the associated stability required; yet still be economical.

HB Engineering Corporation undertook a contract to build a system for automating the reading of private utility meters using the existing private subscriber telephone systems as the data transmission link. By today's standards, the acquisition of four or five decades of data from a remote location via a voice grade wire link already connected by the telephone company's system is a rather mundane task. No question about it; that is, until you become aware of the severe limitations imposed by it being imperative that your data transmission in no way jeopardizes the principal function of this system, the subscriber's own personal communications. Added to this are severe economical boundaries. Together, these two requirements have so far made the task impractical for many reputable firms which have attempted an assault on this huge market potential.

There were other difficulties put in the path of a successful system. Among these was the need for the "black box" at the meter location to be totally passive, even though there was ample power at the utility meter and, with limitations, on the telephone line as well. If matters weren't tough enough, it was also required that the unit had to look non-existent to any normal telephone activity and test condition, except during that brief interval while the meter is being read.

After extensive review of the history of previous attempts, we concluded that a system based on tone signaling was the most appropriate approach. However, to make the system come up to the abnormal performance standards and down to the abnormal economic requirements it was apparent that the new form of low frequency resonators we mentioned previously was needed—now. Therefore, we set out to evolve the TWINTRON.

The objectives set forth for the TWINTRON were that it be an exceptionally efficient resonator, with a high Q (which has a relationship to its efficiency), that it must be unaffected by outside influences, i.e., shock and vibration, and be economical to manufacture in very substantial quantities.

This might be a good time to discuss Q, which is the factor that determines the degree of a resonator's ability to be selective to one specific frequency. Q is defined in filters as the ratio of the center frequency of the response curve to the total bandwidth at the half power, or the —3db points.

Obviously, the higher the Q, the better able the filter is to reject frequencies other than its resonant frequency which is, after all, the measure of the "quality" of the filter. It expresses the ratio of energy stored in the reactive parts of the system to the energy which is dissipated. It is much the same in mechanical resonators; i.e., it is an expression of how much energy is retained and conserved in the resonating device (tuning fork, coil spring, etc.) as compared to how much energy is dissipated into other places and lost. The mechanical Q is, in a sense, an expression of the "quality" or efficiency of the mechanical resonating system. To carry this further, the mechanical Q of the resonant system bears a very direct relationship to the Q factor expressed for the electromechanical frequency filter which will be produced from the mechanical system. Other factors will combine with the initial mechanical Q of the resonator to determine the Q of the resulting filter, including the degree of coupling of energy into and out of the system. The degree of coupling is largely a matter of design and choice of coupling devices or transducers needed to provide certain specific characteristics in the filter's circuit application.

The maximum possible Q of the filter is limited by the energy which will be dissipated and lost in the resonator system as a whole. It includes the losses in the electrical output. Obviously, the higher the energy loss, the lower the Q. It is only from this initial starting point that the filter designer or user can begin to exercise options on coupling techniques, impedance matches, etc. Some of this energy loss results from the internal friction in the

resonator, air dampening of the moving members, inefficiency of the transducer, etc. In most cases, however, the largest single contributor to the energy loss is that tendency of almost any classic mechanical resonator to impress its vibration onto its mounting base. The energy that imparts any motion to the base structure is completely lost.

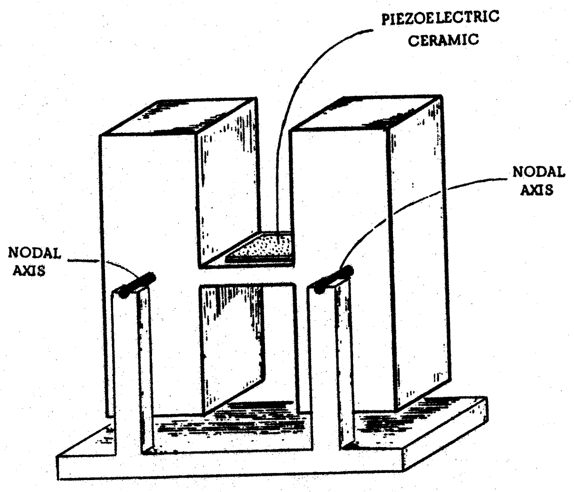


FIGURE 1

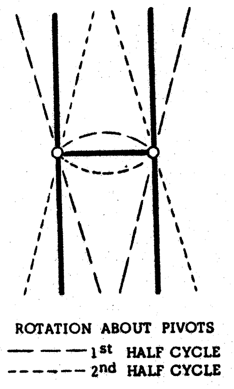


FIGURE 2

The three classical forms of low frequency mechanical resonators: the tuning fork, the cantilevered beam and the simply supported beam, each have nodal points. They are designated as amplitude nodes because they are points of least deflection in the mechanical member. They are not points of zero motion. There is invariably some slight rotation about these nodal points. There is also a substantial degree of lateral motion caused by the reaction to the movement of the mass in the vibrating system. The greatest efficiency is achieved when the resonator is mounted at these nodal points, but still, all the lateral motion is unavoidable imparted to the mounting base of the structure. Even though it is kept to a minimum, a significant amount of energy in the resonating system is given up to the surrounding structure with the subsequent reduction of the efficiency and the Q of the resonator.

This energy exchange is a two-way street. Energy originating in the mounting structure in the form of externally created shock and vibration can be impressed into the resonant system even if it is not at the resonant frequency of the system. In this same way, two adjacent resonators can activate or "talk" to one another. The use of foam rubber or other vibration absorbing materials to isolate the assembly from its base helps avoid transmission of the energy from one resonator to another or from outside influences into the resonator, but it does so by absorbing the energy, not conserving it.

A look at the TWINTRON (Figure 1) reveals the principal difference between it and the other resonators. The parallel "bars" of the TWINTRON are required to be stiff, nonflexing masses. They are equal in mass and dimension to one another and are balanced, each about its own center or "nodal axis" as shown. The contribution of these "bars" to the resonant properties of the system are exclusively mass moment of inertia, i.e., effective mass at a distance from the center of rotation about their respective nodal axis. The "web" interconnects the two rigid "bars" in the plane established by the two nodal axes. It is a relatively low mass, thin spring. For all practical purposes, the sole contribution of the "web" to the resonant system is its spring characteristics.

Therefore, the effects of mass have been almost totally isolated from the effects of the spring. Since spring and mass are represented by separate members of the structure, many significant advantages regarding thermal characteristics are realized, a significant difference from a tuning fork. Each portion of the tine of a tuning fork contributes mass and spring properties inseparably. If you alter one, you unavoidably alter the other. The separation of spring and mass also offers the advantage of being able to mechanically adjust the resonant frequency of the TWINTRON.

The piezoelectric ceramic transducer bonded to the flexing web of the TWINTRON expands and contracts with each half cycle of the applied signal, creating a bimorphic arrangement with the web. The entire web is stretching and contracting as it goes through its cycle, so it does not tend to impart lateral motion in the nodal axis.

When the TWINTRON web flexes, the assembly goes into oscillation in the mode depicted in Figure 2. It is apparent that the two "bars" are in balanced rotation, each about its own nodal axis, and that the pair are moving in opposition to each other. The nodal axes rotate only; there is no lateral motion.

The rotation about the axis is only a few minutes of arc. If the nodal pins are left free to rotate, the rotational motion is not imparted outside of the system. A convenient and very satisfactory mounting arrangement is made by inserting the thin nodal axis pins in moderately firm rubber. The circumferential displacement in a pin of only .020″ diameter rotating through ten minutes of arc is, for all practical considerations, zero. While this mounting affords some protection from physical damage from a severe shock to the case of the TWINTRON, the rubber is not required for the mechanical isolation found necessary in other mechanical resonators. In fact, if the nodal axis pins are fixed firmly to the mounting base, the only change is that the torsional spring characteristics of the pins is added to the

spring stiffness of the web in the overall resonant system. Since they would express counter rotation in a common plane of the mounting base, the net result is still zero reaction outside of the system. Virtually no energy would be given up in the base.

Except for molecular friction, air dampening, and other low order losses, the TWINTRON is able to retain all the energy inside its resonant system and to be impervious to outside mechanical influences. The TWINTRON simply cannot be excited by striking its mounting base or container. While this may upset the piano tuner, it provides the advantages necessary to make highly selective, highly efficient, and economical to manufacture tone filters and resonators for stable tone generators.

As mentioned previously, the resonant frequency of the TWINTRON can be adjusted mechanically. This is easily accomplished by drilling and tapping threaded holes running the entire length of the two "bars." Into each "bar" is put a balanced pair of threaded slugs which are positioned to be at equal radius from the nodal axis which is the center of rotation. As long as these two slugs are kept in balance about their axis of rotation, the immunity of the TWINTRON to shock and vibration is preserved.

Since the position of these threaded slugs affects the mass moment of inertia of the "bars," the resonant frequency is increased as they are adjusted toward the center of rotation and lowered as the slugs are moved outward. This simple method achieves a range of 20 to 30% shift of resonant frequency.

The Q of the TWINTRON is preserved as long as the radius of all four slugs is kept equal. The Q may be deliberately reduced by making the radius of the slugs in one "bar" different from those of the other. Each "bar" is still balanced, but they will have different mass moments of inertia. They will tend to move out of phase with each other and thereby broaden the frequency response characteristics of the resonator as a whole.

We have recently extended the range of mechanical adjustment of the resonant frequency by designing "bars" with inside and outside threads. This permits a large shift of the resonant frequency by changing internally. threaded sleeves around the outside of the "bars," while permitting a vernier adjustment with the threaded internal slugs. A model is being produced which can be so adjusted over the entire voice band (300 to 3000 Hz). The Q of this TWINTRON can be adjusted from approximately 50 to 200.

The ability to tune a single filter over a wide range of frequencies offers a significant advantage to manufacturers of tone control and communication equipment who use a multitude of different frequencies. Instead of inventorying quantities of filters at all the various frequencies, they may now inventory a limited quantity of a single TWINTRON model which can be easily adjusted to the required frequency by the equipment manufacturer himself. The economic improvement compounds itself. While the total number of filters remains the same, the number of different parts is reduced to only one basic unit.

The TWINTRON can be excited and sensed by any of the typical transducers that are associated with the classic resonators (except, of course, externally generated vibration). Generally, electromagnetic and magnetostrictive transducers are used with better quality classic resonators. They exert the least amount of extraneous influence of the resonant system since they do not physically contact the resonator.

Relatively few electromechanical resonators use piezoelectric transducers, even though they are highly efficient and offer an excellent mechanical impedance match to a high Q resonator. Some of the reasons become clear when one considers the amount of piezoelectric material that would be required to get full coupling into and out of a tuning fork for example. It has two tines, both of which are in motion throughout their entire length. It would be relatively expensive to convert all of this motion into electrical signal by covering a large portion of the tines with piezoelectric material. In addition to the expense, the influence of the inherently low Q, low stability ceramic material on the mechanical characteristics of the tine would be great. On the TWINTRON, however, all the flexing is done in a single, relatively short, stiff spring. The mechanical coupling is nearly perfect. Efficiency of the system goes up again. The size of the piezoelectric material is small, so its influence on the spring properties is kept to a minimum. Consequently, the problems of compensating for the thermal characteristics of the piezoelectric ceramic material are reduced.

Using piezoelectric coupling, we can obtain multiple isolated electrical outputs and inputs since each piezoelectric ceramic wafer offers an individual input or output transducer. Piezoelectric material has a polarity sense. It can be arranged and used much like the polarity sense of a transformer winding. The piezoelectric ceramic wafers can be arranged to be in phase or 180° out of phase with each other at resonance. By arranging them so that the input and output signals are 180° out of phase, a simple frequency stable oscillator circuit can be designed without phase shifting networks in the circuitry (Figure 3).

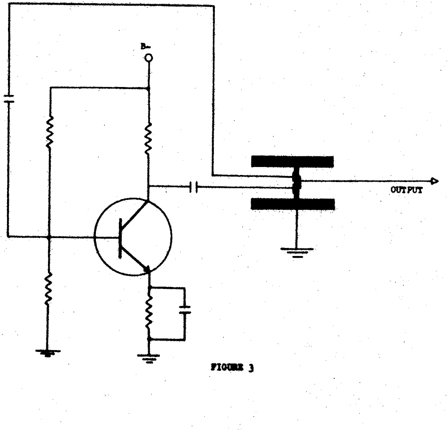


FIGURE 3

To avoid loading the single transistor oscillator circuit and thus pulling its frequency, a third piezoelectric ceramic is used to provide an isolated output. The stability of the oscillator is greatly increased since the entire oscillator circuit is virtually isolated from the effects of the next stage. The TWINTRON provides its own built-in buffer.

By arranging the piezoelectric transducers to reverse the phase relationship of the input and output signals, rejection filters are made by simply arranging a resistor shunt path for the signal.. The resistor value is selected so that the signal passing through it is equal to the signal from the output transducer at resonance. For all frequencies other than the resonant frequency of the TWINTRON, the path of these signals is through the resistive element only. There is no signal from the output ceramic transducer. At the resonant frequency of the TWINTRON, there is a signal from the output transducer which is summed at the junction of the resistor. This signal, being equal to but out of phase with the signal passing through the resistor, causes complete cancellation, thus creating the notch in the characteristic response curve as shown in Figure 4. Since there are no reactive elements in the circuit the response across the entire spectrum from DC is flat.

There are many obvious uses for frequency rejection filters. One of the more unusual ones is in improving the apparent accoustical qualities of an auditorium, sound studio, etc. It has been found that in many cases only a limited number of specific frequencies contribute to the various undesirable accoustical properties of the room or area. By removing these nuisance frequencies in the amplification systems, the sound in the area is "cleaned up." The highly selective characteristic of this rejection filter and its flat pass characteristic produces no detectable ill side effects in the quality of the sound system. The value of the shunting resistor can be altered slightly to give control over the depth of the rejection notch. Therefore, the objectional frequency can be merely reduced, or totally eliminated.

Of course, one frequency that most often comes up as a candidate for rejection is 60 Hz and its harmonics. We are now in production of 60-Hz rejection filters. Our model TR60 is 2″ x 1½″ x 1⅛″ high. The rejection characteristics of the TR60 are shown in Figure 5. It represents the first practical solution to what has been a thorn in the side of communication, instrumentation, and hi-fi engineers for years. Piezoelectric ceramic material has inherently high impedance characteristics, particularly at low frequencies. Therefore, there is a significant insertion loss when this filter is worked into a low impedance load. Most of our users prefer to work the TR60 into a field effect transistor which provides both an excellent impedance and some power gain (Figure 6) with no DC offset.

Any TWINTRON can pass or reject its resonant frequency. By building it with an input and two separate output transducers (only one of which is connected via a shunting resistor to the input), the TWINTRON can simultaneously pass and reject its resonant frequency. The shunted output passes all frequencies but the resonant frequency from its output lead. The second output transducer passes no frequency but the resonant frequency from its output lead.

The ability to provide isolated piezoelectric outputs makes possible floating differential outputs. Such a property is useful in the narrow FM discrimination circuit shown in Figure 7.

A unique property of piezoelectric ceramic is that its elastic properties change as the effective electrical load on it changes. Since in the piezoelectrically driven configuration, the elastic properties of the TWINTRON spring web, it is possible to effect a variation in the resonant frequency of the TWINTRON of approximately ±1% by the simple circuit shown in Figure 8. By calibrating the variable resistor, a highly selective filter or oscillator can be shifted over this range by a known amount. Or, by using a properly selected thermistor, a high degree of thermal compensation can be realized. A zero temperature coefficient is theoretically possible.

On the subject of thermal compensation and frequency shift, the TWINTRON "bars" and web can be made of different materials to achieve optimum thermal properties. This also offers several significant economies in manufacturing ease and material cost. We use commonly available, nonexotic aluminum and steel alloys to achieve

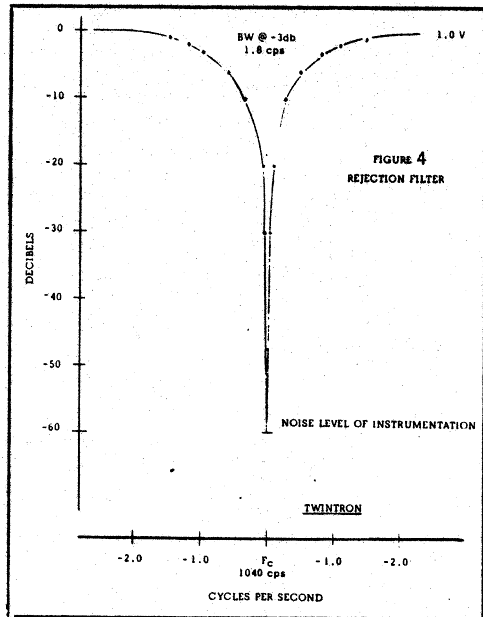


FIGURE 4
REJECTION FILTER

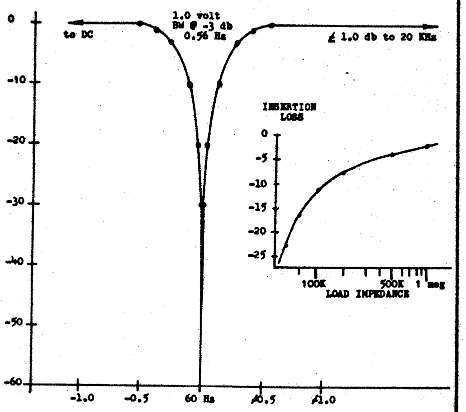


FIGURE 5

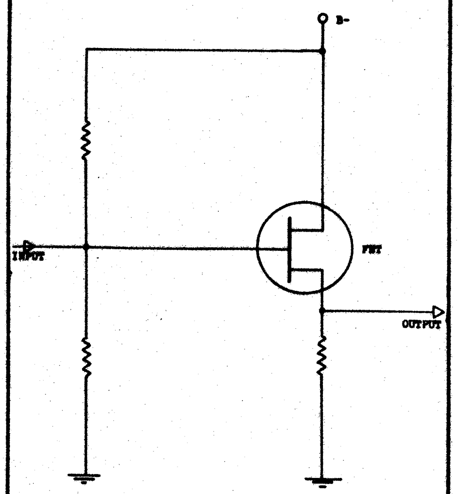


FIGURE 6

better than .05% stability over the —40 to +55° C temperature range in our volume production TWINTRONS. By carefully selecting the alloys, the thermal stability can be tailored to virtually any requirements, regardless of the Q required in the resonator.

We have dwelled on the value of using piezoelectric input and output transducers. We have nothing against other forms of transducers. We use electromagnetic and electrostatic transducers where a requirement demands a Q exceeding 3000 or more. And, of course, many of the design and performance characteristics we've described can also be achieved with these other transducers. In fact, many of these characteristics were previously possible only with nonpiezoelectric transducer forms. But they were accomplished without the economy and efficiency of the piezoelectrically driven TWINTRON.

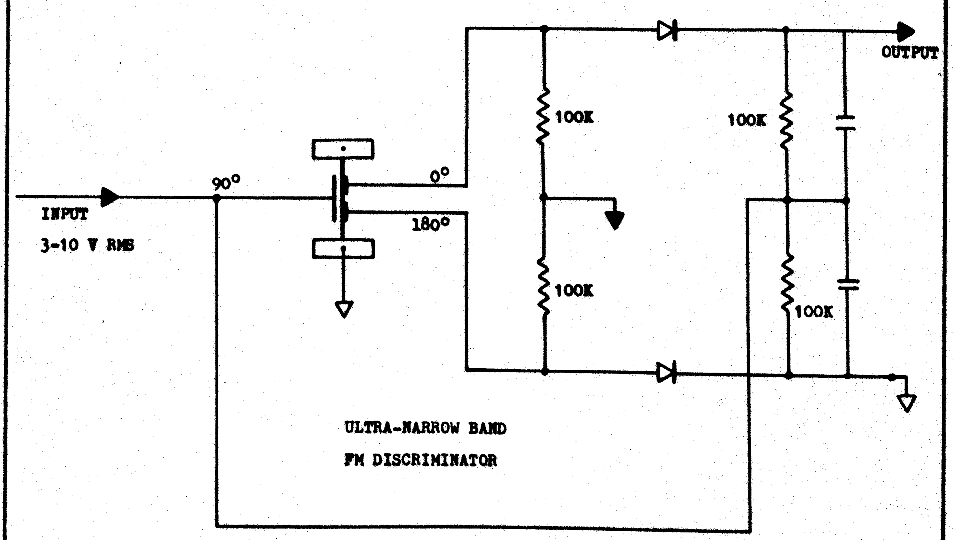


FIGURE 7

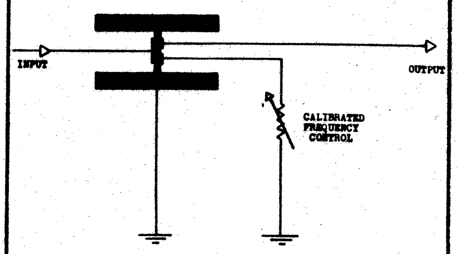


FIGURE 8

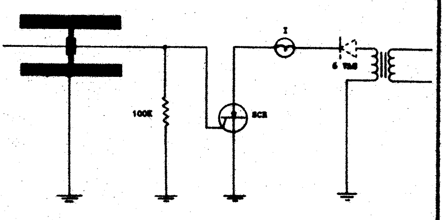


FIGURE 9

While the piezoelectric ceramic transducer is inherently a high impedance device, particularly at low frequencies, it is capable of delivering substantial signals into low impedance loads. When properly matched, a voltage gain can be achieved from input to output. Two to one is not an uncommon ratio. The piezoelectrically activated TWINTRON is a linear device from a few microvolts to about two volts of signal level. Above this there is some slight nonlinearity and a tendency to reduce Q. It will not be damaged by signal levels as high as 40 volts. We typically operate around the 0.5 to 1.0 volt signal level. At these levels, a single SCR circuit (Figure 9) can be used to operate lights, relays, activate solenoids, etc., direct from the output of the TWINTRON. By putting a diode in series with the AC voltage on the indicator, it, of course, becomes a "hold" indicator, staying on once triggered until the lamp circuit is opened. This simple circuit is extremely useful in almost any tone control or select calling system.

As mentioned before, we are able to attain Q's in excess of 1000 with relative ease. This means that such a TWINTRON filter can readily discriminate between two frequencies one Hz apart at 1000 Hz, or two which are 0.1 Hz apart at 100 Hz. For comfort and convenience, frequency separation is generally kept farther apart than that in complex signaling systems. Even so, we can push well over 1000 separate channels into a voice grade communication link with reliability. Attaining a Q nearing 10,000 takes a little more care in mounting and the use of another form of transducer, but it can be done. This has been particularly interesting to people doing cardiac and neurological research. Dealing with the subaudio frequencies (1 to 10 Hz), conventional passive filters have been hard pressed to reach a Q of 10.

Going back to why it all happened, we have evolved several systems which take advantage of the TWINTRON's unique properties. Bear in mind that the TWINTRON is perfectly well suited for all the typical functions to which electronic and electromechanical resonators have been used previously (except twanging by piano tuners). But we have taken advantage of and have patents pending on several unique systems which require no active elements at the remote site of the network. Nor do the re-

mote stations require any power except the normal signaling tones typically carried over wire or radio links. There are many obvious advantages to a system which incorporates passive devices exclusively, reliability being the first generally thought of. These systems also turn out to be very impressive when economy is looked into. Regardless of how system cost is derived, any of the TWINTRON systems proves to be substantially less expensive than any conventional means for performing the same function.

One of the more simple and most interesting ones among them we have called the "Echo System." It is capable of determining simple "YES-NO" conditions at a multitude of remote sites. By using high Q TWINTRONS (approximately 500 to 1000) we are able to set up over 1000 remote stations on a common voice grade communication link. This compares favorably with the 30 channels normally considered full capacity on a similar link with conventional techiniques.

Each channel has a simple TWINTRON controlled oscillator or transmitter (similar to Figure 3), a TWINTRON filtered channel receiver and a completely passive TWINTRON resonator conected to the two wire transmission line via a switch which determines the "YES-NO" conditions at the remote site. All channel transmitters and all channel receivers are switched alternately to any duplex communication link via a mechanical or solid state chopper which is used for a T/R switch. During the transmit interval of the T/R cycle, the TWINTRON at the remote site receives and stores energy at its resonant frequency. During the receive interval, the remote TWINTRON "echoes" the stored energy at its resonant frequency back into the transmission link and into the corresponding channel receiver to trigger on the indicator or relay as long as the switch at the remote site is closed.

If the switch is opened, no stored signal energy is received during the receive interval and the indicator goes out immediately. It stays out until the remote switch is closed. There is no scanning. The maximum time between the change of the "YES-NO" condition and the corresponding change in the indicator for any channel is one half the total T/R period, 8 milliseconds for a 60-Hz chopper, less than 2 milliseconds for one operating at 400 Hz. There is also a slight decay period required for the TWINTRON in the channel receiver.

As mentioned in the description of the SCR circuit (Figure 9), if this is an alarm monitoring system, the indicator can be made to remain on once triggered until manually reset. It is inherently "fail safe." When necessary in the system, a single amplifier is used by all transmitters and all receivers for impedance match to the line and to provide some receive signal gain.

A similar system can provide a visual or audible alarm at the remote site without any power required other than the signals on the transmission link. In it, a fixed frequency (2 KHz for example) is placed on the line. This is the signal which will power the indicator or actuate a piezoelectrically driven disc howler. The fixed 2-KHz frequency is on the line constantly, but it cannot actuate any of the remote indicators until a signal frequency, the one used to identify the called station, is passed through the TWINTRON filter at that station to switch on an SCR in the circuit from the transmission line to the indicator. Having the actuating power originate from the central station of the signaling system avoids intermingling two power sources. In addition, it provides a selective communication system where no power is available at the remote location. Of course, voice communication can be carried on the line once the called party "picks up" the line. We feel that many rural telephone systems will find this helpful since it may enable them to drastically reduce the wire size by eliminating the current carrying capacity required for the ringing current. In fact, it is not unreasonable to have such systems go to AC signaling completely and eliminate the need for DC voltages as well as the heavy AC ringing current.

A minor modification of this system gives an extensive private system an intercom capability. That is, any one of a multitude of stations on a single common link can selectively call any other station, all without power at the various stations.

Another system which is useful in extensive networks like turnpikes, pipelines and railroads, enables a central station to ascertain, with absolute certainty, that AC power is or is not present in beacon lights, highway lighting, control valves, etc. While the "echo-system" can perform this function via a secondary input, such a relay or switch contact acting in conjunction with the power switch, it is not able to positively determine if the bulb filament is burned out, valve open circuited, etc.

In this "AC power monitoring system," the remote site will use a pair of TWINTRONS and a simple diode mixer. A designated tone for a given station (1000 Hz for example) is put on the line at the central station. It is passed through one of the TWINTRON filters at the remote station which is tuned to pass the 1000 Hz tone. The output of this TWINTRON filter is applied to one input of the diode mixer. The other input to the mixer is the AC power frequency (60 Hz) signal provided from a simple current transformer or capacitor pickup in an appropriate circuit location. The two frequencies are mixed and the sum or difference frequency (1060 or 940 Hz) is passed through the second TWINTRON filter which is tuned to either of these "reply" frequencies which have been derived by this frequency translation technique. The "reply" frequency (1060 Hz for example) is put back on the transmission link and de-

tected at the central station. Therefore, whenever this particular remote station is interrogated by a 1000-Hz signal and a 1060-Hz signal is returned, it is a certainty that 60 Hz AC power was present at that remote site. Channel separation can be as close as with the "echo system."

For example, to check another remote station, an interrogration frequency at 1002 Hz may be used, which will generate a "reply" tone of 1062 Hz. Channel capacity is reduced to 50% (500 channels on a voice grade link) because one frequency is used to interrogate and a second one, which is the interrogation signal displaced by the power line frequency, is used to verify the presence of power in each separate location. But, the determination is absolute and instantaneous since all remote stations can be monitored simultaneously and continuously.

For those people who are concerned with taking real data: meter readings on tank farms, weights in batching systems, flow rates in pipelines, etc., there is another somewhat more sophisticated system. We are still talking about passive, unpowered remote units, operating on a single two way link (wire or radio), and we are still talking about economical systems, ones for industrial users to whom a dollar is a measure of worth. We call this one our PRT System (Passive Remote Telemetry, Figure 10).

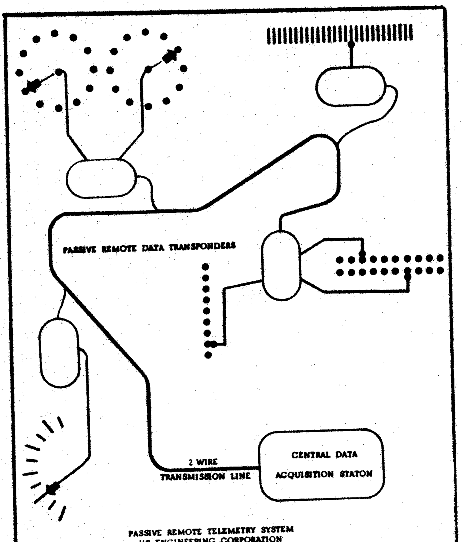


Figure 10

The PRT System is capable of telemetering data from a multitude of remote stations. The data can be in any numerical format: binary, decimal, etc. It is typically generated in shaft position encoders, counter commutators, or solid state switches. In such systems, the data are typically generated in decimal form. So we generally describe the system capacity in number of decades without regard to their location along the link. In the case of a voice grade link, 100 decades of data can be telemetered. The decades can be arranged in any combination at any number of remote sites. The 100-channel capacity can be 100 single decades, 5 decades at 20 remote stations, etc. If the link quality is increased to 8 KHz, the system capacity is increased to 1000 decades. In many cases, it is practical to share some of the remote hardware by using sub-stations and thereby achieve even greater economy.

The PRT System uses a combination of frequency and time division multiplexing. At the remote sites, frequency translation is used, eliminating the need for hybrids on wire links.

In the typical PRT System, four tones generated at the central interrogation station are designated as encoding tones. With simple wire encoding of the signals derived from a set of multiple output TWINTRON encoding filters at the remote site, the correct combinations of these encoding tones are put on the individual segments of the decade switch or shaft encoder. At the same time, four sets of interrogation tones are generated at the central station in sequence. The frequencies of these interrogation tones are selected so that they will join with the encoding tones in diode mixers in the remote unit to produce "difference" frequencies or "reply" tones.

A separate mixer and TWINTRON filter tuned to a specific "reply" tone fequency is associated with each decade wiper arm of the mechanical switch encoder. The occurrence of a "reply" tone at the central station during the application of a specific interrogation tone indicates a given encoding tone is present on the decade being interrogated. All four groups of interrogation frequencies must be sequenced through before the number in a given decade is determined. But, simultaneously, all the decades are interrogated in this way so that at the end of each sequency of four groups of interrogation tones, all decade values are determined at the same time. Therefore, the maximum upgrading time of the data from any and all decades in the system is the period of the four groups of interrogation tones regardless of the number of decades in the system. Typically, this is one-tenth to one-half second.

In a slightly different configuration, the system can be made to telemeter each decade individually so that the numeral in any decade selected can be determined with a single interrogation tone set. In this manner each decade would have to be telemetered one at a time, but it offers the advantage of being able to be selective in which decades are monitored.

There are a few other things being kicked around in our lab. For example, following the theory that if one is good, two ought to be better, we have begun work on TWINTRONS having a multitude of bars or bar pairs. In effect, this creates a variety of mechanically coupled resonators. There are various phase relationships which can be best preserved when a group of TWINTRONS are tightly coupled by virtue of having them share a commmon nodal axis pin or shaft while being stagger tuned to create a wide bandpass characteristic.

Another variation of the multibar TWINTRON is used to create a highly selective accoustical driver and sensor. In certain applications, it is advantageous to have a multitude of bars, not necessarily in pairs. The efficiency of the piezoelectric transducer tends to improve and certain interesting phase

relationships can be developed in the bar motion. The piezoelectric transducer is bonded to the web which is now in the form of a disc instead of a flat spring as in the more typical TWINTRON. The inside of the walls of the bars are contoured to follow an exponential curve and create in effect a pair of back-to-back cones. As the contoured bars vibrate about their nodes, accoustical energy, sonic or ultrasonic, is radiated in both directions from the plane of the web. Since the two are out of phase, it is often best to direct one half of this radiated energy into absorptive material to avoid a cancellation.

At the resonant frequency of the assembly, the unit is an exceptionally efficient accoustical device. Then, of course, the same device works in reverse to become a highly frequency selective accoustical microphone or pickup. The principle advantage of having a frequency selective input sensor is the improvement in the signal to noise ratio at the input to the accoustically controlled device. Many intrusion detection security systems may take advantage of the improved sensitivity offered by the accoustical TWINTRON resonator.

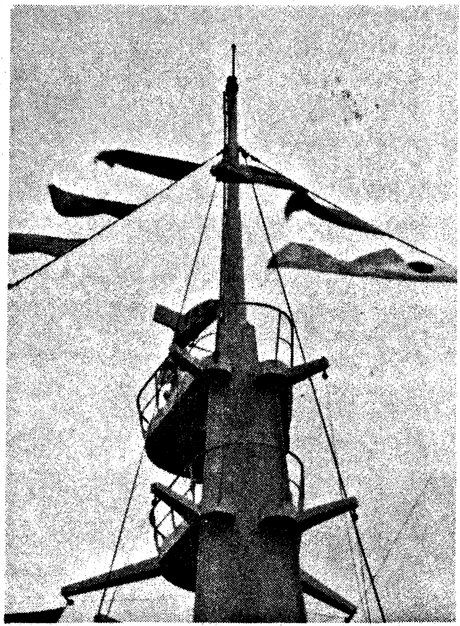
The multibar TWINTRON has other interesting facets. There is no particular limitation on the number of bars or whether the number is odd or even. If the bars are all equal in their mass moment of inertia, there is a significant improvement in the Q of the resonator. However, if the bars are not cut so as to have equal mass moments of inertia, several interesting wobulation effects take place due to the variations in the phase relationship of each bar to the system as a whole.

The wobulation characteristics of this multibar TWINTRON may open an interesting range of new potential applications. It is possible, for example, to obtain an output signal of almost any phase relationship to an input signal at or near the resonance of the TWINTRON. This may be done by cutting the individual bar length as a sawtooth function, i.e., each bar slightly longer than the adjacent one in one direction. On the disc web, a single piezo electric wafer is used as the input transducer—but the disc-shaped wafer on the output side is segmented into a series of electrically isolated pie-shaped segments —each one adjacent to one of the bars. If the shortest bar is the one actually in resonance at the input frequency, each of the progressively longer bars will move somewhat later—or delayed in phase from the shortest bar. Consequently, each of the associated piezoelectric segments will produce an output which is delayed from the input signal in relationship to the length of the bar to which it is adjacent.

It is apparent that in such an arrangement, the motion of the individual bars is related to the electrical output from the associated piezoelectric segments. Both mechanically—(looking at the motion created by the moving ends of these bars) and electrically, these multibar TWINTRONS can be made to resemble Lissajous patterns. One such pattern—the slow rotation of an elliptical shape, can be made to create a frequency divider. It is particularly interesting because the divisor can be continuously variable and not limited to discrete steps or whole integers.

Other applications still on our drawing board include a timepiece motor using the TWINTRON not only as the frequency stable time base, but also as the control drive mechanism. Many of you must have already wondered about light choppers—or laser modulators. Yes, we've looked into these too.

The tuning fork has been around for about 150 years. Reeds and other mechanical resonators have been around even longer. The TWINTRON is still very new. Most of our time has been spent trying to learn the "nature of the beast." It has been interesting doing something new in one of the oldest fields of electronics. Based on what we have learned so far, we're looking forward to the next item we'll be able to pull out of the TWINTRON'S bag of tricks.



TIMES HAVE CHANGED

Since some club members pounded brass at sea, there have been changes in marine radio. From CW, emphasis has gone to AM phone and now to SSB and VHF/FM phone. The compact VHF antenna on top of the mast of the S.S. Rotterdam is shown in the photograph above.

A CHRISTMAS STORY OF YEARS, TOWER, AND OSCILLATIONS

by

G. H. CLARK

1881 AND ITS RURAL PHONE
When I became what was to be,
Our daily words of mystery
Came to us through an iron wire
Thrilled by a dim electric fire,
The ether lay in lazy ease,
Save for the lightning's pleasantries.

1888; THE HERTZ OSCILLATOR; 1.4 METERS
My mileposts from initial heaven
Had added up to total seven
When Hertz, our wireless first "than whom"
Received his blitz-spark, room to room.
Thus in this humble laboratory
Wireless first lisped its little story.

1895; MARCONI'S BAMBOO MAST; 40 METERS
A lad of mere fourteen was I
When 'neath the fair Italian sky
The ether's virgin vast domain
Was harnessed to commercial gain.
With almost childish ceremony.
Was this achieved by young Marconi.

1901; MARCONI'S KITE AERIAL; 800 METERS
Life's escalator bore me on
Till I attained my wireless dawn,
Basing my puny amateur story
Upon my hero's greater glory.
It seemed t'was almost I who won
The Atlantic's conquest, just begun.

1902; SHIP'S MASTS; BACK TO 300 METERS
First voter was I, on the morn
That Navy radio was born.
Ship's masts took eager place on shore;
The spark gap, with deafening roar;
The tortured ether felt the blow
Of wireless hammers housed below.

1911 BRINGS WOODEN TOWERS AND 2000 METERS
The arc transmitter found our shores,
And Elwell's latticed two by fours
Uprode the California air
To free a new transmission there.
Six hundred feet o'er golden ground.

1912; THE NAVY'S SELF-SUPPORTING TOWERS; 3800 METERS
Then came the pride of Navy's Way—
Three towers topping NAA,
And here the spark, its span outrun,
resigned to an imprisoned sun.
Poulsen to Elwell passed to Clark
The final burial of the spark.

1915; THE GRID GROWS GREATER
A tiny lamp of flashlight size
Lay hidden from commercial eyes
For many years. But now its might
Grew to a giant's, overnight.
De Forest's audion became
Radio's first and greatest name.

1918; TUBULAR MASTS; 13,600 METERS
But for the moment, in its span
From child's estate to sturdiest man,
It yielded to a giant disc
At maximum speed, with minimum risk.
Alexanderson's alternator
Bowed, in its day, to nothing greater.

1920; BROADCASTING; BACK TO 300 METERS
Came Conrad, by De Forest led
To complete the word by Fessenden said.
McCarthy's intellect was ours
From countless wire-connected towers.
Mae West antennas sought the sun,
And Mae once gave us Eden's fun.

1940; MY OSCILLATIONS ARE GETTING FEEBLE
Today I'm old, and weak, and deaf;
I can't hear WEAF (That's some DEAF)
My Heaviside Layer (to be blunt),
Is mostly out in front.
This screed contains full many a wheeze,
But I have other types than these.

CLUB NEWS

Walter Lyons has left for Singapore on a consulting assignment and plans to return by the end of the year. **John Finley** has been appointed Club treasurer, succeeding **Joe Stantley** who resigned. **Stuart F. Meyer** (W2GHK), **Carroll B. Vaughn** and **Dr. J. B. Johnson** have been elected *Fellow* members of the Club. Dr. Johnson is the famous Johnson of *"Johnson Noise"* whose original paper on the subject dates back to 1928.

Radio Club Has New HQ

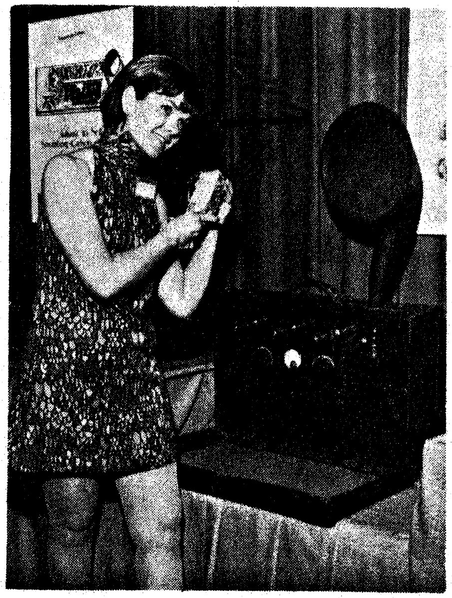
The offices of the Club are now located in Room 604 at 250 Park Avenue, New York, N.Y. 10017, telephone (212) 986-6596.

Communications Conference Set For December 5-8

The 1967 IEEE Vehicular Conference will be held at the New York Hilton Hotel. Registration begins and exhibits open on December 5. Technical sessions will be held on December 6, 7 and 8. Papers will cover the latest advances in vehicular radio communications.

The Radio Club of America will be one of the exhibitors and Club members David Talley, Fred Link, Julian Sienkiewicz and Leo Sands are serving on the conference executive committee. All club members are invited to attend.

ARE YOU IN THIS PICTURE? These are the members and guests who attended the 57th Anniversary Banquet on November 29, 1966. W. W. "Wally" Watts, group executive vice president of RCA, was the master of ceremonies and Bruce Kelley of Eastman Kodak put on a great audio-visual show depicting the history of radio.



The first portable superheterodyne receiver, built by Harry Houck, was one of the top attractions at the first Consumer Electronics Show, sponsored by the Electronic Industries Association, which was staged in New York in June. The Club also exhibited other antique radios.

MEMBERSHIP DRIVE

The club is looking for new members. Application forms are available from Stuart F. Meyer, P.O. Box 6527, Raleigh, North Carolina 27608, chairman of the membership committee.

"HAPPENINGS" AMONG RADIO CLUB MEMBERS—

William J. Halligan, founder of Hallicrafters, recently was honered for his contributions over the past 34 years to the Amateur Radio fraternity. Bob Finlay was selected by the Hallicrafters reps' and sales force, among whom are many "hams," to make the presentation to Bill Halligan. Both are Fellows of The Radio Club. The ceremony took place on June 16th last, at the Watertower Inn, Chicago, where a plaque was awarded, which read:

W9AC/W4AK
W. J. "BILL" HALLIGAN

For outstanding vision and leadership in the advancement of the communications art and serving the radio amateur through successful development and mass production of sophisticated radio communications equipment, which helped to pioneer use of new frequency bands and advanced communications techniques, thus making possible wider use of amateur radio and promoting more effective communication and understanding among all radio amateurs throughout the world.

JOHNSON TO RECEIVE ARMSTRONG MEDAL

At the 58th anniversary celebration banquet, the Armstrong Medal will be presented to John Bertrand Johnson for the reasons cited below.

Citation on the Occasion
of the
Award of the Armstrong Medal
to John Bertrand Johnson

In recognition of his outstanding contribution to the art and science of radio communications.

The juxtaposition on this award of the names of two outstanding pioneers in the field of electrical noise, Johnson and Armstrong, honors both men.

In an active and continuing career of over 50 years John Bertrand Johnsons contributions include, the development of the Western Electric 224 cathode ray oscillograph tube, the discovery and description of thermal noise in circuits and flicker noise in tubes, and numerous scientific papers dealing with the fundamentals of thermionics, field and secondary electron emission, and the basic physics of the solid state.

This award is made in recognition of the debt every communication engineer owes to the man whose discovery of the electromotive force due to thermal agitation in conductors is memoralized in perpetuity as "Johnson Noise".

PROCEEDINGS PAPERS 1959-1966

The following is a list of papers published in the Proceedings from 1959 through 1966. Those published earlier are listed in the 50th Anniversary Year Book.

Vol.	No.		Author
		1959	
35	1	General Review of Missile Telemetry An Account of the Discovery of Jupiter as a Radio Source	Dale Samuelson K. L. Franklin
35	2	Problems of Ballistic Missile Defense	W. R. Hutchins
		1960	
36	1	The Evolution of Radio	Hugo Gernsback
36	2	Golden Jubilee Anniversary Number	
		1960-1961	
37	1	Super Regenerative Pulse Radar The Writing of Radio History—A Project for RCA	Frank H. Shepard, Jr. I. S. Coggeshall
		1961	
37	2	The CBS NetALERT—A System for Network Signalling	A. A. Goldberg A. Kaiser and G. D. Pollack, CBS Labs and D. Vorhes, CBS Radio
37	3	The Anatomy of an Electronic Typer	Walter Hladky
37	4	A New Method of Accurate Frequency Measurement	Harry W. Houck and Norman W. Gaw, Jr.
		1962	
38	1	The Dynaquad, A solid State Electronic Switch	C. E. Atkins
38	2	Philips Telegraph Switching Systems	E. R. MacMillan
38	3	Simplified Automation	Ralph R. Batcher
		1963	
39	1	The Teleglobe Pay—TV System	Ira Kamen
39	2	The Importance of Reliability and Maintainability of Electronic Devices	S. R. Calabro
39	3	New York's Modern Fire Communications Center	N. J. Reinhardt and A. Dettori
		1964	
40	1	Portable TV Tape Recorder N.Y. Fire Communications Center (part 2)	F. J. Haney and R. L. Pointer N. J. Reinhardt and A. Dettori
40	2	Optimizing High Frequency Telegraph Transmission	Walter Lyons
40	3	Whales, Porpoises and Sonar	William E. Schevill
40	4	Membership Directory	
		1965	
41	1	The Modulated Optical Alarm System	Samuel M. Bagno
41	2	The Oscar Amateur Satellite Program Educating Systems	Nicholas K. Marshall Ira Kamen
41	3	Computer-Produced Movies Application of Time-Diversity to Multi-Link Data Transmission	Kenneth C. Knowiten Walter Lyons
		1966	
42	1	Communications to the Moon and Planets	Eberhardt Rechtin
42	2	Mosquito Metrology and Communications	William H. Offenhauser and Peter Williams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