Early Warning Monitoring Method, System and Apparatus for Television and FM Radio Transmitting Antennas and Coaxial Feedlines

ABSTRACT

A computer-controlled monitoring apparatus processes measurements of four signals: power transmitted to the antenna I^2, power reflected from the antenna R^2, power radiated from the antenna $T^2$and arc voltage A that would be reflected back and forth between the antenna and the transmitter. The monitor provides early warning alarms of arcing or overheating in the feedlines to the antenna and inside the antenna long before a catastrophic failure has occurred and the transmitter is forced to shut down by its own protective circuit. Early warning of developing failures allows for orderly transition to standby transmission facilities and for timely maintenance without losing on-air time in the event of catastrophic failure. The monitoring apparatus also provides a failsafe indication of whether or not power is delivered to the antenna and whether or not the antenna radiates the power delivered to it. Such failsafe indication is required before maintenance personnel are allowed near the antenna. The apparatus described here measures the relative power density at specified locations near and on the tower and compares the measured density to that allowable by the Federal Communications Commission (FCC). The monitoring apparatus can be applied to multiple transmitters with multiple channel combiners feeding a common antenna connected to the transmitters with one or two feedlines.

BACKGROUND OF THE INVENTION

The vast majority of television and FM radio broadcast stations employ pressurized coaxial feedlines that deliver the power from the transmitter to the antenna, which is located on a tower whose height may be up to 2000 feet above ground level. The antenna itself may contain additional coaxial lines and power splitters, all of which comprise the power distribution system to individual radiators of the antenna. A coaxial feedline is made of concentric inner and outer tubular metallic conductors with multiple internal connectors.

Any of the multiplicity of components comprising the power delivery system from the transmitter to the radiators comprising the antenna can fail catastrophically. A catastrophic failure is evident by a burnout within the power delivery system. A burnout can extend to several hundred feet of the feedlines, depending on when the transmitter is shut down after the onset of overheating or arcing. While the burnout is in process, the transmitter continues to deliver the power to maintain the burnout. At some later point, when a significant portion of the incident power is being reflected back from the damaged area, the transmitter protective circuit senses the reflected power level and automatically shuts down the transmitter.

The causes for the onset of arcing or overheating, culminating in burnout, vary. For example, a loss of pressure allows moisture to enter the coaxial feedlines thereby increasing the probability of arcing across the insulators that keep the inner conductor concentric with the outer conductor. The arcing carbonizes the insulators, thereby causing undesired dissipation of a portion of the power transmitted to the antenna by the insulators. Excessive dissipation of power inside the feedlines is a precursor to catastrophic failure. Other causes of catastrophic failure are tower sway and excessive movement of the inner conductor due to internal or external temperature variations. Improper design, faulty manufacturing and poor installation have also been identified as causes of failure in feedlines.

Once initiated, arcing and overheating may persist over weeks or months before a catastrophic failure materializes. The cost of replacement equipment and lost advertising revenues due to off-air time related to catastrophic failure is substantial. It is therefore very important to avoid catastrophic failure through early warning during the onset of arcing or overheating.

Prior to the present invention there have been no systems and methods that would provide reliable early warning of arcing or overheating in TV and FM broadcast antennas and their feedlines. Priors to the present invention, failure reporting methods have been based solely on measuring the power (or voltage) being reflected back toward the transmitter, sometimes together with measuring the loss of gas pressure inside the feedlines. Those methods provided protection for the transmitter from power reflected back but did not prevent the transmitter from continuing to power supply to the overheating or arcing areas inside the feedlines until after the burnout was almost complete. That is because while power would be supplied to the failing areas, only a small portion of it, if any at all, would be reflected back and so the damage would continue to increase until a catastrophic failure materialized. Only near or after catastrophic failure would a significant portion of the power intended for the antenna be reflected back toward the transmitter, tripping the transmitter’s protective circuit thereby causing the transmitter to shut down.

SUMMARY OF THE INVENTION

The present invention provides an effective means for early warning resulting from overheating or arcing in the coaxial feedlines of broadcast antennas for TV and FM radio. It does so by simultaneously monitoring for arcing inside the coaxial feedlines and for changes in the level of power radiated by the antenna (or dissipated in the feedlines). The monitored levels are continuously being compared with the expected (nominal) levels of lost power in the feedlines and the level of power reflected back toward the transmitter during normal operation. Unexpected deviations from nominal power levels are treated as alarms.

The present invention also provides for a failsafe determination of which antenna, within a complex of several antennas is radiating and also the power density level emanating from each radiating antenna at specified locations on the ground or on the tower. Such monitoring allows the broadcaster to ensure compliance with FCC regulations and also to protect maintenance personnel and the general public from excessive Radio Frequency (RF) exposure.

The monitored power levels are collected by up to four probes per TV or FM channel and are processed and a local computer that translates the processed signals into alarms. One of the four probes is a consumer-grade rooftop antenna. This antenna would typically be mounted on the roof of the transmitter building. The output power available from that rooftop antenna is proportional to the radiated power. Thus, any loss of power intended for delivery to the transmitting antenna would be either in the form of lost radiated power or increase on the power reflected back toward the transmitter. The consumer-grade antenna would detect loss of radiated power and a directional coupler on the feedline to the transmitting antenna would detect the rise of reflected power. For the present description of the method it can be assumed that the nominal loss of power prior to the onset of failure is zero and therefore that the equation governing the relationship between incident I^2, reflected R^2 and radiated T^2 power is:

$$(1)\left(\frac{T}{R}\right)^2 = \left(\frac{I}{R}\right)^2 - 1$$

Thus, if the values of R^2 and I^2 are known from calibrated measurements, the ratio $(T/R)^2$ will decrease during overheating if <u>either the reflected power increases or the radiated power decreases</u>. During overheating, the reflected power can only increase and the radiated power can only decrease. Prior to the onset of failure, the ratio $(T/R)^2$ is independent of the power delivered by the transmitter. Therefore, the ratio of $(T/R)^2$ can serve as a failure metric regardless of the transmitter's operating power. More specifically, if

$$(2) K_0 = \left(\frac{R_0}{T_0}\right)^2 \text{ and } K(t) = \left(\frac{R(t)}{T(t)}\right)^2$$

are, respectively, the ratios during normal operation and during failure in progress, then overheating alarm would be indicated if:

$$(3) \frac{K(t)}{K_0} > 1$$

The probes for the incident I^2 and reflected R^2 powers can be two independent directional couplers or a single bi-directional coupler. Either coupler is standard equipment normally supplied as part of the transmission equipment purchase. If a bi-directional coupler is used, only three probes are required. During installation of the transmission equipment, the incident I^2 and reflected R^2 powers are calibrated so that R_0^2 and I_0^2 and thus K_0, are known.

During normal operation, the RF exposure levels, expressed in mW/cm^2, would be measured at several locations on and around the tower. The measured levels are proportional to the radiated power. Therefore, any variation in the transmitted power would linearly translate into proportional change in the previously measured exposure levels. Exposure alarm would be indicated if

$$(4) \textit{Measured RFR Exposure} \geq \textit{FCC Allowable Limit}$$

In the above equations, (t) indicates that the calculated or measured variable is a function of time. Climbing on the antenna would be prohibited as long as for each channel radiating from that antenna $T^2(t)>0$ or $I^2>0$.

For N antennas, all within proximity of each other, climbing would be permitted only if:

$$(5)\ T_1^2 + T_2^2 + T_3^2 + \ldots\ldots\ T_N^2 = 0 \text{ and}$$

$$I_1^2 + I_2^2 + I_3^2 + \ldots\ldots I_N^2 = 0$$

The specific design of the arc detection probe is also a part of the present invention. The arcing phenomenon produces irregular pulses of electromagnetic radiation, visible flashes, and ozone gas. The present invention focuses on the detection of the electromagnetic pulses produced by arcing. The most significant frequencies that constitute these pulses, the frequencies carrying most of the arcing power, are below 10 MHz. Because of the low frequencies, most TV and FM antennas are unable to radiate the power produced by arcing. Thus the electromagnetic energy created by the arcing remains confined inside the coaxial lines between the antenna at one end and the filter/switcher equipment, which is near the transmitter, at the other end.

To detect arc voltage A, two new probes are included as part of the present invention. One, a narrowband probe, could be used for a single channel transmission system. A second, a broadband probe, would be used for a transmission system of multiple channels with a common feedline from the transmitter to the antenna. Naturally, the use of the broadband probe for single channel applications is not excluded.

The output voltage of the arcing detection probe is connected to the alarm circuitry through an opto-isolator to prevent high-voltage pulses from damaging the processing and alarm electronic circuits. The arcing voltage is used to generate both audible and visual alarms. Once arcing or overheating alarm is triggered, the incident power I^2 is lowered, manually or automatically by the computer, until $K(t)/K_0 <= 1$ until the arcing alarm ceases.

The system and apparatus comprising the present invention allows for simultaneous local and remote computer control. The remote control, whether vial telephone, wireless or through the World Wide Web, can be established by using commercially available components and software. In case of multiple channels and multiple antennas all at the same site, the local computer would communicate with a master computer. A master computer is necessary in order to monitor the power radiated from each antenna and each channel and provide go/no-go decision before climbing on the tower for repair or maintenance.

BRIEF DESCRIPTION OF THE DRAWINGS

The preferred embodiments of the present invention will be described based on the following, wherein:

Figure 1 is a simplified schematic diagram that shows the apparatus comprising the monitor for a single-channel broadcast transmission system. The power to be monitored is generated by the transmitter **17a** and is passed through filter **17b**, to feedline **4,** which connects to a broadcast antenna **16**. Directional coupler **1** provides voltage proportional, respectively, to the power I^2 transmitted to the antenna and the power R^2 reflected back toward the transmitter. Receive antenna **2** provides voltage proportional to the power T^2 radiated by broadcast antenna **16**. Probe **3** provides voltage proportional to the arcing power A^2. The voltages proportional to I^2 R^2 *and* T^2 are sequentially switched into a spectrum analyzer **9** for relative power is measurement by a logic control circuit **10** and switches **8a, 8b, 8c**. The switched voltages are thus in the Pulse Amplitude Modulation (PAM) format. Probe **3** is made of coaxial line whose inner and outer conductors connect to the inner and outer conductors of line **4**. The arcing voltage is extracted by tap at a point on the inner conductor of probe **3** which is away from the junction of probe **3** and feedline **4** at a distance which is odd number of ¼ wavelengths of the monitored channel. The extracted arcing voltage A is first passed through a low-pass filter **6** and then through an opto-isolator **7**. The output of the opto-isolator is then passed through an integrating A/D (analog to digital) converter **13** to computer **15**. After power measurementat the spectrum analyzer **9**, the voltages proportional to I^2, R^2,T^2 are also converted from analog to digital format by the A/D converter **12** and are then input to computer **15.** Computer **15** assesses the acquired levels in accordance with formulas *(1)-(5)* above and displays alarms as they are detected. When arcing is detected, an audible alarm can be additionally heard by tapping voltage A and feeding it to a voltage/frequency converter **14**. All of the apparatus except for the remote control of computer **15** are housed in one building near the broadcast tower. A clock **11** supplies the time signal to the A/D converters **12** and **13** and to the logic controller **10**.

Figure 2 is a simplified schematic diagram that shows the apparatus comprising the monitor for a multi-channel broadcast transmission system. Because several channels are combined via multiplexer **19** on a single feedline connecting to a single transmitting antenna, a unique and broadband arcing probe **18** is required to sense the arcing voltage A without affecting the transfer of power to the transmitting antenna. The arcing probe **18** must be located between the antenna **16** and channels multiplexer **19** because little if any arcing power would be radiated by the broadcast antenna or passed through multiplexer **19** back to the transmitter. The arcing probe **18** provides the same arcing voltage A to each station's monitor. The voltages proportional to the incident power I^2 and the reflected power R^2 are channel-specific. Therefore, bi-directional coupler **1** must be located between each transmitter and multiplexer **19**.

In addition to having a different arcing probe, the computer monitor of each channel's communicates with a master computer, where the decision regarding safe climbing condition is being made based on the input from all individual computers.

Figure 3 is a simplified schematic diagram that shows how the broadband arcing probe **18** is configured. It is made of an internal metal rod antenna **20** designed to capture the low frequency components (<10 Mhz) of the arcing pulses and placed inside a section of feedline **4**. Rigid coaxial feedline sections for broadcasting are typically 20 feet long and the antenna **20** extends through most that length. The antenna **20** is surrounded by insulator **21**, which provides mechanical support to the inside of the outer conductor.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows how the voltages proportional to I^2, R^2, T^2 and A are sampled. The voltages proportional to I^2 and R^2 are sampled by bi-directional coupler **1** and the voltage proportional to T^2 is sampled though a direct connection to a nearby receive antenna **2**. The sampled signals are each passed through channel filters **5a**, **5b** and **5c** that reject extraneous out of channel voltages. A logic-controller **10** commands switches **8a**, **8b** and **8c** to sequentially convert the continuous analog voltages proportional to I^2, R^2 and T^2 into Pulse Amplitude Modulated voltages. The three voltages are squared and then integrated and the resultant powers are continuously displayed. The resulting powers of I^2, R^2 and T^2 are then digitized by the A/D converter **12** and logged in computer **15** for further processing in accordance with the algorithm *(1)-(5)* shown in the SUMMARY OF THE INVENTION section. The sampled voltage A is first passed through a low-pass filter **6** and is then connected to an opto-isolator circuit **7** whose function is to transmit the signal forward through light fluctuations rather than through hard-wire connection. In the event of high voltage arcing, hard-wire connection from the probe to the computer might cause permanent damage to the computer and the other electronic circuits shown in Figures 1 and 2. The output of the opto-isolator **7** is connected to an integrating analog-to-digital converter **13** and also to a voltage-to-audible frequency converter **14**. The output of the integrating analog-to-digital converter **13** is proportional to the average power of the arcing and it is logged in computer **15** for further processing in accordance with algorithm *(1)-(5)* shown in the SUMMARY OF THE INVENTION section. The audible output of the voltage-to-frequency converter **14** is amplified and connected to a loudspeaker. Digitizing circuits **12** and **13** and the logic control **10** for switches **8a**, **8b**, **8c** are synchronized by clock **11**.

The arcing probe **3** is designed to extract only the low frequency arcing pulses. In particular, it is constructed to tap the arcing signal at a point where the voltage of the broadcast channel is essentially zeroed. The special design calls for the probe to be constructed of a coaxial feedline whose typical length would be, but need not be, an odd multiple of 1/4 of the broadcast channel's wavelength. The inner and outer conductors of the probe **3** could be open or shorted at one end. At the other end, the inner conductor of probe **3** is connected the inner conductor of feedline **4** and the outer conductor of probe **3** is connected to the outer conductor of feedline **4**. If the coaxial line comprising probe **3** is shorted at one end, then the tapping point for the arcing signal is integer multiples of ½ of the broadcast channel's wavelength from the shorted end of probe **3**. As shown by the dotted lines next to probe **3**, the tap position is the zero voltage point at the broadcast channel frequency and thus only non channel-related signal will be provided to low-pass filter **6**. If the coaxial line comprising probe **3** is open at one end, then the tapping point for the arcing signal is odd integer multiples of ¼ of the broadcast channel's wavelength from the open end of probe **3**.

Figure 2 shows the additions and changes required relative to Figure 1 to monitor N channels that are multiplexed on common feedline(s) **4** and a common antenna **16**. Each of the N channels has its own separate transmitter and all are connected to a common multiplexer **19**, which combines all channels into common feedline(s) **4**. Each channel has its own early warning monitor. Each monitor must be supplied with the channel-specific voltages proportional to I^2, R^2 and T^2 and also by the arc voltage A, which is common to all channels.

When combining several channels on common feedline(s), the channel-specific arcing probe **3** would not be used because 1) it cannot maintain wideband impedance match at its junction with the common feedline, and 2) because it cannot maintain zero voltage at all frequencies at any tap point along the probe **3**. To overcome the shortcomings of the narrowband probe **3**, a new wideband probe **18**, detailed in Figure 3, is implemented in Figure 2.

The wideband probe **18** shown in Figure 3 is a metallic rod antenna **20**, less than 20 feet long, inside a section of a standard coaxial feedline. That rod antenna **20** is open at one end and is physically separated from the inside of the outer conductor by insulator **21**. The length of the rod antenna **20** and the separation distance between it and the inside of the outer conductor of the coaxial feedline **4** are adjustable and their choice dictates the magnitude of the voltage A, which is proportional to the arcing voltage. The voltage A is tapped from one end of the rod antenna **20** and is connected to the filter **6**.

The voltage A induced in the arcing probe **18** is first passed through a low-pass filter **6**, which insures that voltages I and R are blocked and only the voltage A, induced by arcing, is passed to the opto-isolator **7**. The output of the opto-isolator **7** is divided equally among the N monitors, one monitor per channel.

When several channels are multiplexed on one antenna, common monitoring of arcing and radiation exposure is required. Therefore a master computer is added. The master computer communicates with the computer **15,** which is dedicated as a channel-specific early warning monitor. The master computer, which collects voltages proportional to I^2 and T^2, is dedicated to making the decision regarding safe climbing condition based on the input from each individual channel computer **15**. The decision regarding the allowable transmitter power when arcing is detected is also the responsibility of the master computer, which gets the arcing alarm from each channel computer **15**.

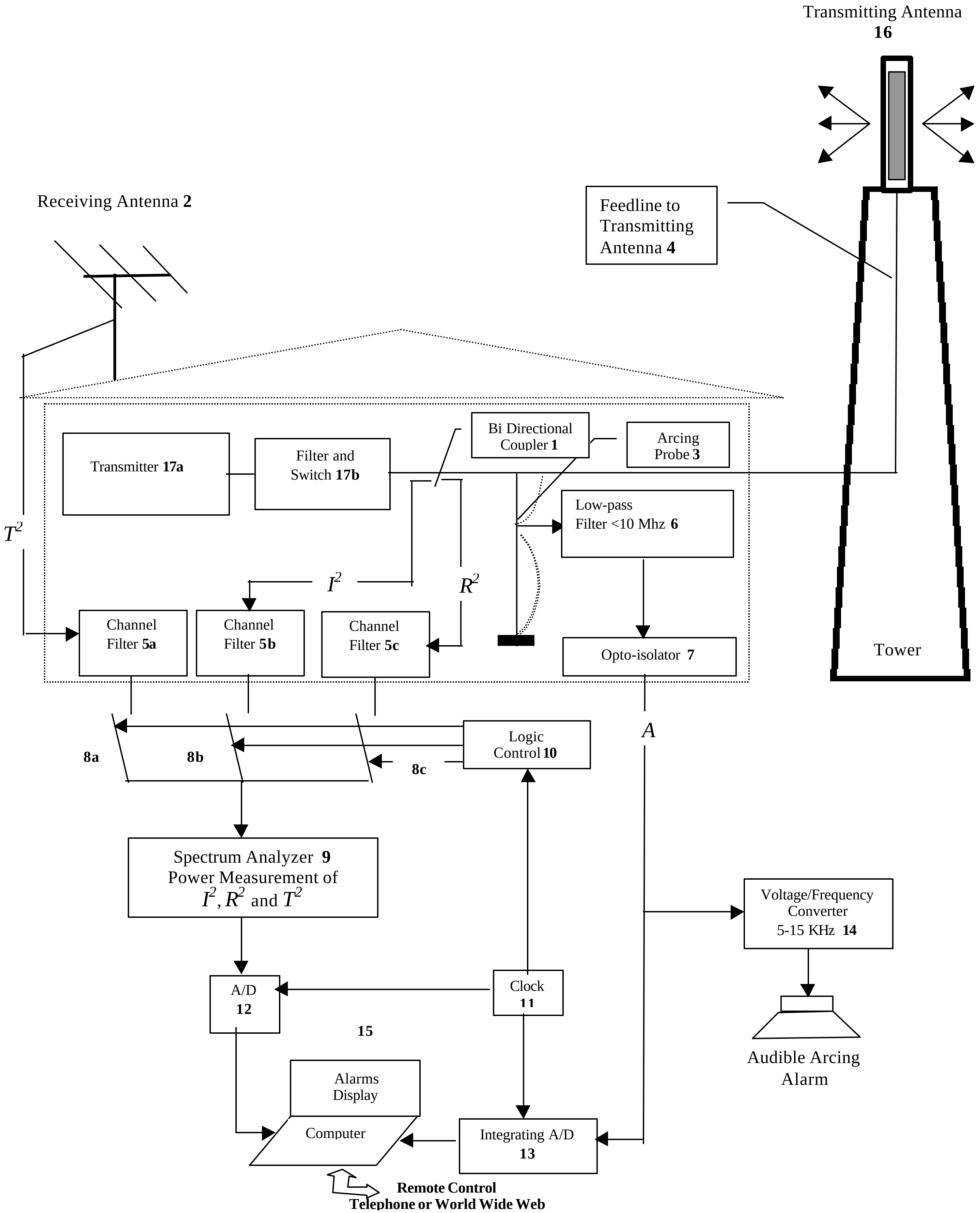

Figure 1: Single Channel Monitor

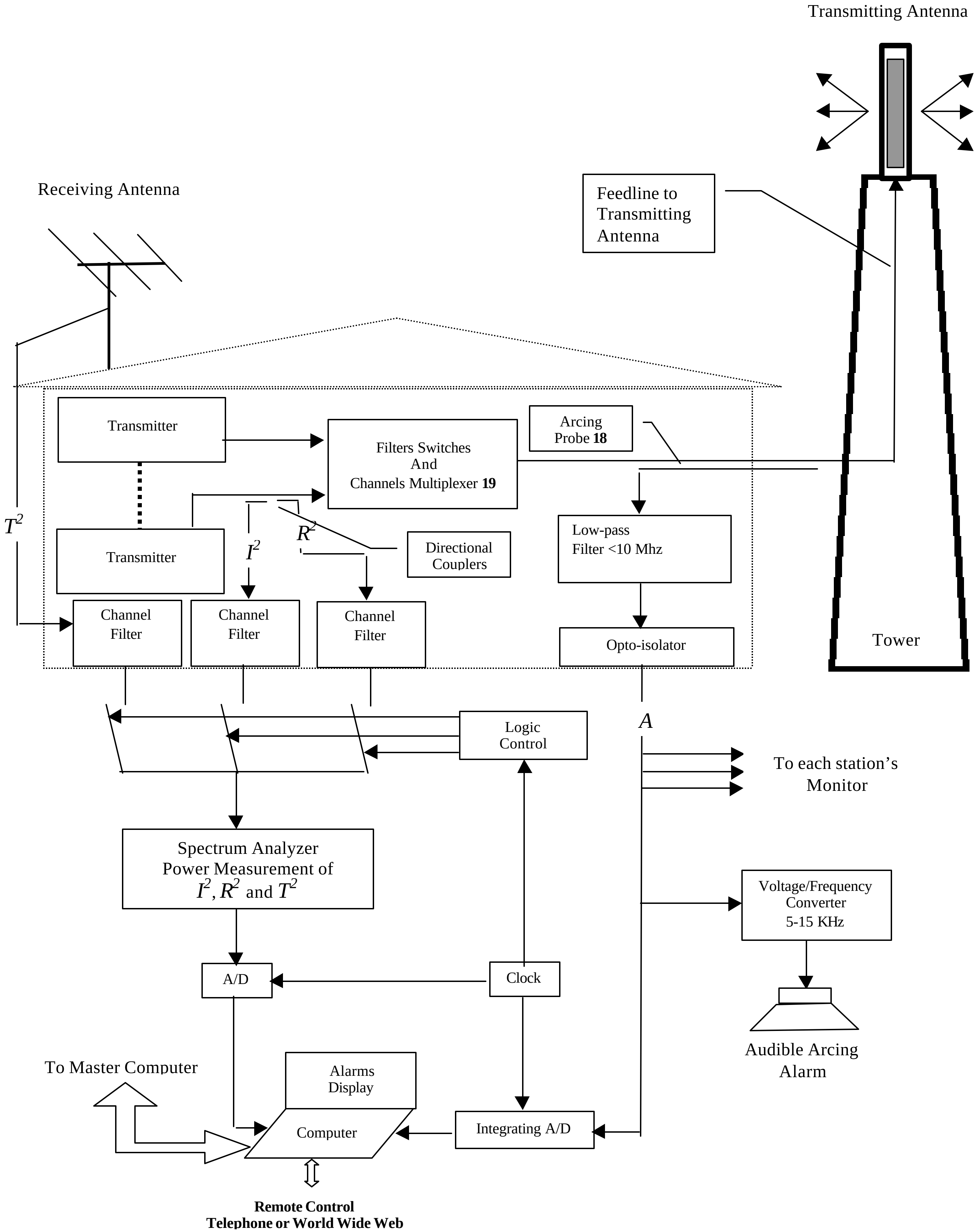

Figure 2: Monitoring Multiplexed Channels on One Antenna

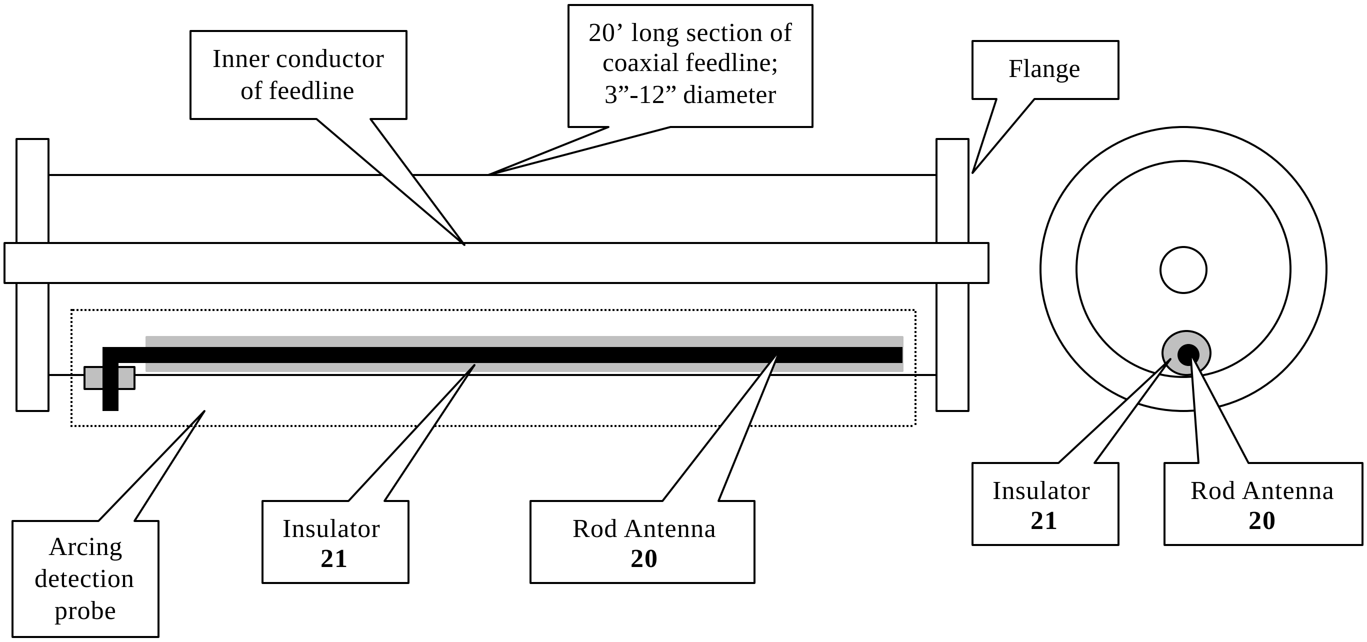

Figure 3: Front and side views of the broadband arcing probe