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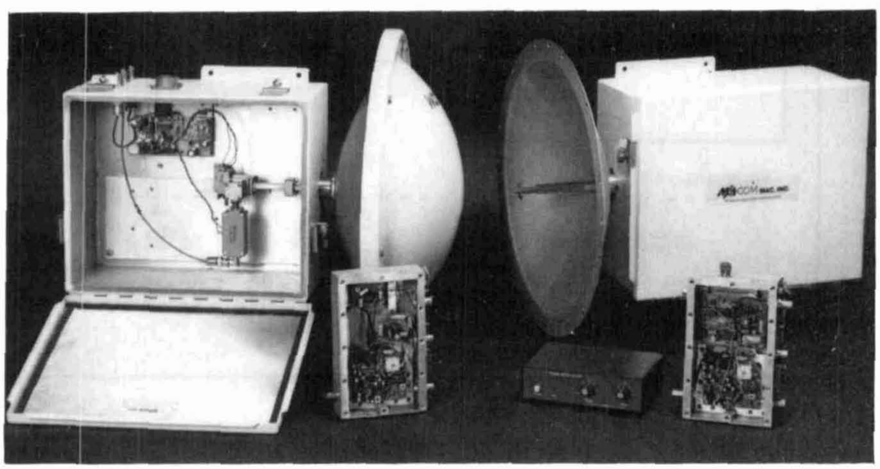
A COMMUNICATIONS SYSTEM USING GUNNPLEXER TRANSCEIVERS

Want a fast and easy way to get on the microwave bands? Here's a scheme that uses Gunnplexers™ and inexpensive portable (Walkman™) stereo radios.

A former Cornell Amateur Radio Club president, who now works in the microwave industry, donated a pair of 24-GHz M/A-COM Gunnplexer™ transceivers for our use. These Gunnplexers are similar to the MA-87127 series, which are popular with hams, but operate at 24 instead of 10 GHz. We wanted to put them on the air with a minimum of hassle and circuit building. We tried using FM radios for the IF/AF circuit, as suggested in the MA-87127 data sheet and *The ARRL Handbook*,[1] but immediately discovered two problems. First, the Gunn oscillators drifted with time and temperature, so the FM radios required constant adjustment. Second, the Gunnplexers'100-MHz IF signal overloaded the front end of the FM radios, resulting in poor audio quality. To rectify these problems, we modified a pair of inexpensive portable FM stereo radios (Gemini AS10K*), used a analog AFC circuit to keep the two Gunnplexers "locked" to each other, and installed a digital circuit which searches out and finds the lock when power is first applied, or if the lock is lost. The result was a high-fidelity communications link for which we have found a variety of uses at W2CXM. We have used the system for such applications as DXing, demonstrations, and as a link between our remotely located 2-meter repeater and the club room.



*Available at many K-Mart stores.

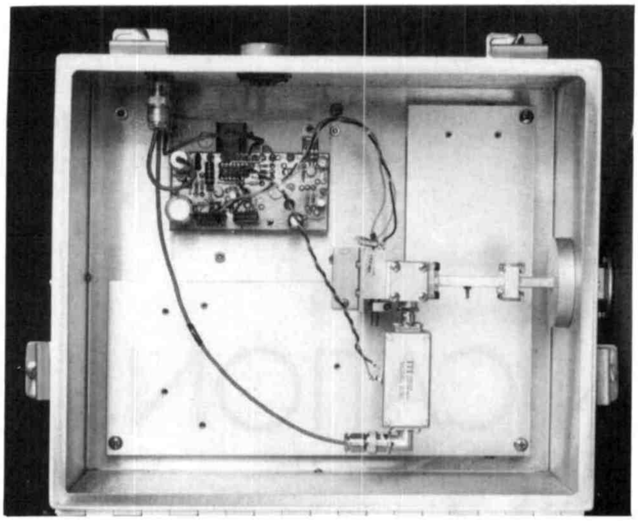


Photo A. A 24-GHz Gunnplexer. From right to left: waveguide tuning screw, circulator, and Gunn oscillator. Just below the circulator is the mixer and IF preamplifier. Above and to the right of the Gunn oscillator is the Gunn diode power supply board.

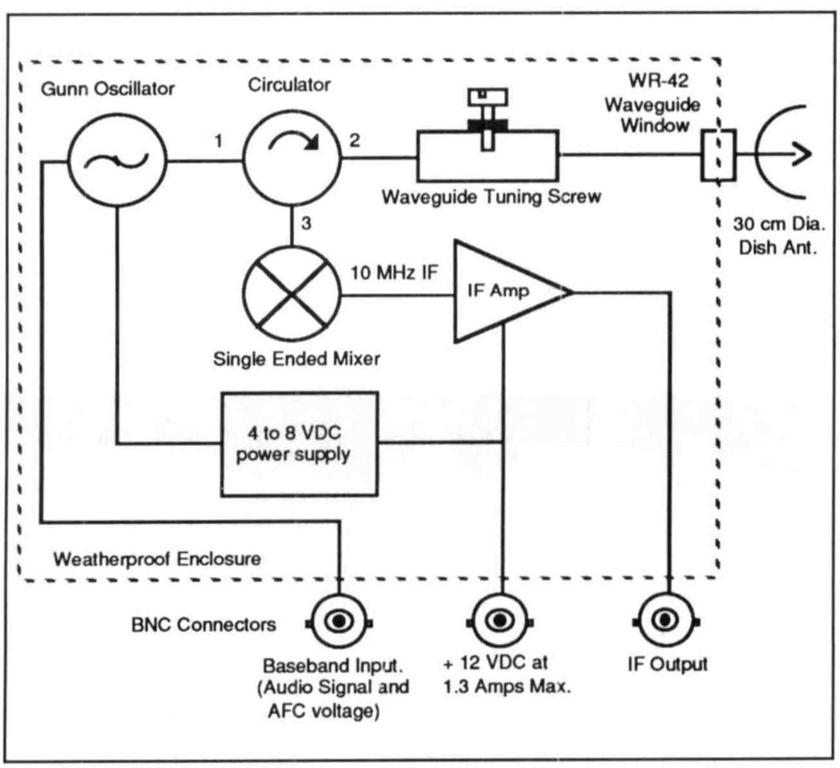


Figure 1. Block diagram of the 24-GHz Gunnplexer.

Gunnplexer Transceiver

Photo A and **Figure 1** show the 24-GHz Gunnplexer and a block diagram. The heart of the unit is the Gunn oscillator. It consists of a Gunn diode mounted in a waveguide cavity. The cavity acts like a very high-Q resonant circuit with a center frequency, in this case, of 24 GHz. Applying a DC bias (4 to 8 volts DC at 1 amp is typical) to the Gunn diode causes the circuit to oscillate at the frequency of the cavity. A mechanical tuning screw on the side of the Gunn cavity lets you shift the center frequency by several hundred MHz.

Gunnplexers are primarily used as the front end for two-way communications. In this mode, two units are used with their carrier frequencies offset by the IF frequency – typically in the 10 to 200-MHz range. The Gunn oscillator acts as a transmitter and a local oscillator for the receiver down-converter, simultaneously. Full duplex is an inherent benefit of this configuration. It allows concurrent reception and transmission – much like a telephone conversation. Most Amateur applications will only require simplex operation. This means that, at any given time, one unit will be used as the transmitter, while the other will act as a receiver down-converter. The transmitted microwave signal generated by the Gunn oscillator travels from port 1 to port 2 of the circulator and past the tuning screw on its way out to the antenna. However, a small amount of the transmitted signal is reflected back by the tuning screw through port 2 to port 3 of the circulator, and into the mixer. This is the LO signal. The incoming signal received by the antenna travels from port 2 to port 3 of the circulator into the mixer, where it's combined with the LO signal to generate the IF signal.

You can apply FM modulation to a tuning varactor mounted inside the Gunn oscillator cavity. The varactor is set close to the Gunn diode in the waveguide cavity, and its input is usually called the baseband input. Any change in the varactor's capacitance due to a modulation voltage, will change the oscillating frequency. The frequency change for the 24-GHz Gunnplexers is on the order of 60 to 90 MHz for a 0 to 12-volt signal at the varactor input (**Figure 2**) – $\simeq 7$ MHz/volt deviation. To keep the IF signal from the Gunnplexers within the 70-kHz bandwidth of the FM stereo radio IF section, apply no more than $\simeq 10$ mV modulated signal to the baseband input. Note that increasing the voltage into the varactor increases the operating frequency. This relationship is essential to the operation of AFC circuit detailed in the next section.

W2CXM Gunnplexer communications system

A diagram of the W2CXM Gunnplexer system is shown in **Figure 3**. The Gunnplexers are offset by the 10-MHz IF frequency. The Gunnplexer set to the lower frequency is controlled by an analog AFC; the upper Gunnplexer is controlled by a digital lock circuit.

Figure 4 helps explain the operation of the analog lock circuit. The output from the FM detector in the KA2248A chip has two components. One is the modulated signal which is fed into the audio circuits (pin 1 of the KA2264 chip) via a blocking capacitor. The other is a DC voltage proportional to the IF frequency, as shown in **Figure 4**. If, for example, the two Gunnplexers start to drift apart, the IF frequency and the DC voltage start to increase. This voltage is fed back into the varactor of the lower Gunnplexer by way of the analog lock circuit (**Figure 5**). Increasing the voltage increases the frequency, so the lower Gunnplexer "chases" after the upper one. You'll get the opposite effect if the two Gunnplexers drift toward each other. The IF frequency begins to decrease, as does the DC voltage feed into the lower Gunnplexer. In other words, it starts to "run away" from the upper Gunnplexer. This is an example of negative feedback. What results is that the IF frequency remains essentially constant, despite changes in the operating frequency. The analog circuit is an excellent way to lock the two units, but its range is limited. Every time power is applied or the lock is lost, the free running or "upper" Gunnplexer must be adjusted until the lock is found.

To eliminate the need to tune one of the Gunnplexers each time power is applied or the lock is lost due to misaligned antennas, we designed a digital frequency lock circuit (see **Figure 6**). The circuit scans the voltage applied to the upper Gunnplexer until a signal appears. This signal is indicated by a digital low voltage at the signal LED driver (pin 7 of the KA2248A chip). The circuit then stops scanning so the analog lock can take over. U3 is configured as a simple digital-to-analog (D/A) converter clocked by an NE555. Its output is buffered by a LM358 and applied to the Gunnplexer's baseband input. The voltage range that U3 can scan is set anywhere over the 12-volt range by the two 1-k resistors at the base of Q4 and Q5. Q4 sets the upper voltage, while Q5 sets the lower one. The 555 is turned on and off by the signal LED driver output of the KA2248A IF chip via the U1 circuit. U1 serves to AND together two different time

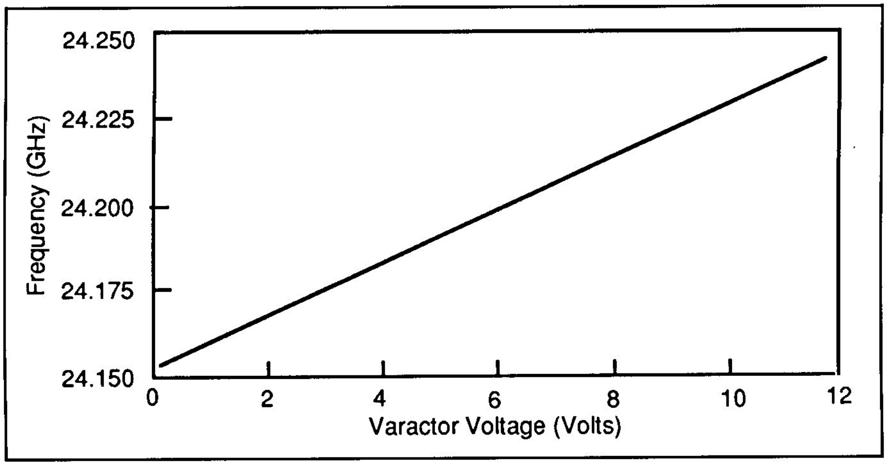


Figure 2. Typical Gunnplexer tuning curve.

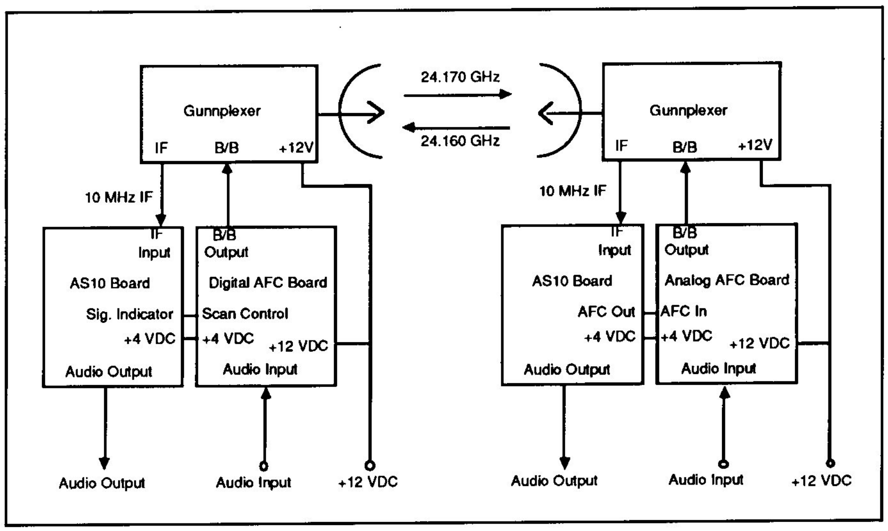


Figure 3. Block diagram of the W2CXM Gunnplexer communications system.

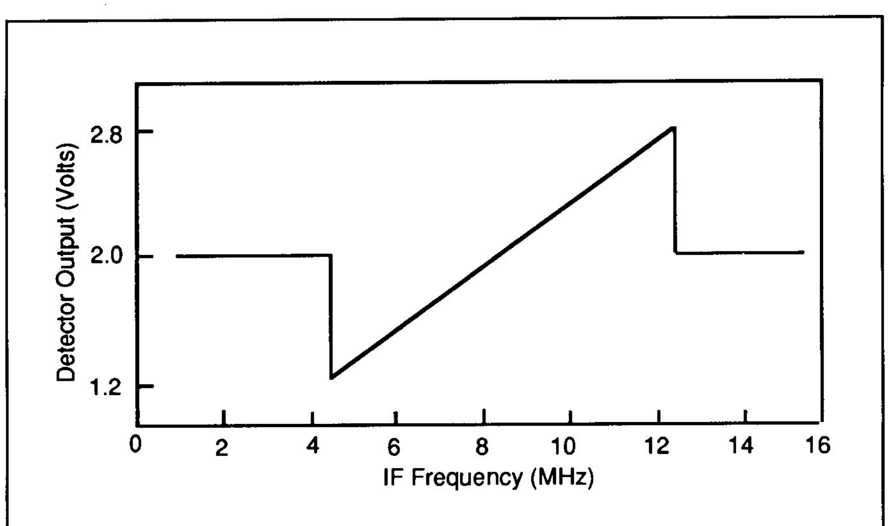


Figure 4. DC output voltage out of the FM detector in the KA2248A chip. Within the range of 4 to 12 MHz the DC voltage increases with the IF frequency. AFC can be performed by feeding the DC voltage back into one of the Gunnplexers.

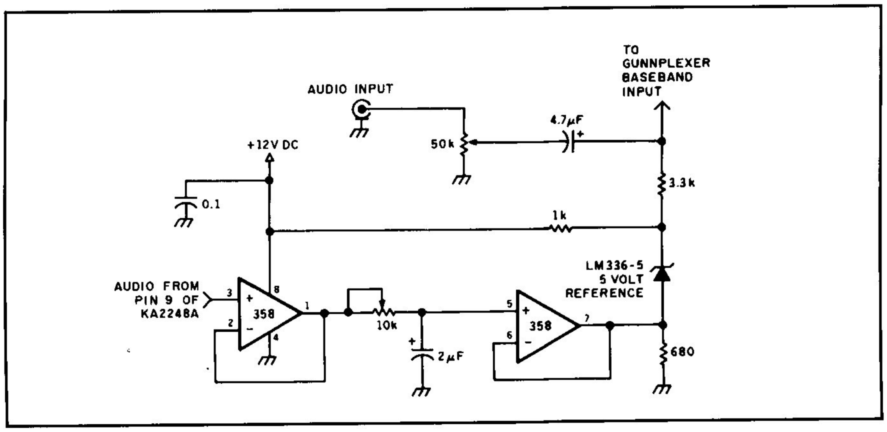


Figure 5. Analog lock circuit schematic. The DC voltage from the FM detector is buffered, filtered, and level shifted up 5 volts before being applied to the baseband input of the Gunnplexer. The 10-k trimpot sets how fast the lock responds to changes in frequency.

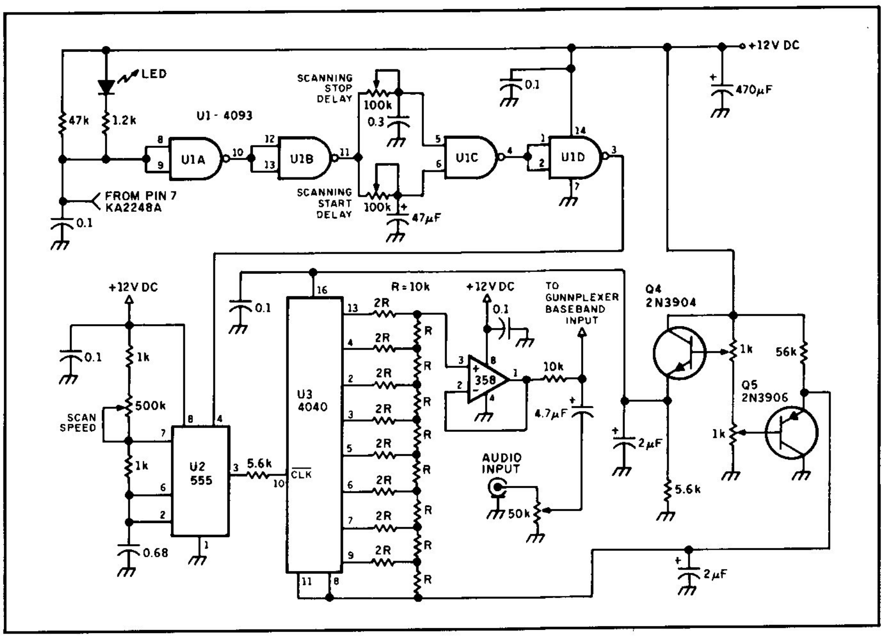


Figure 6. Digital AFC circuit.

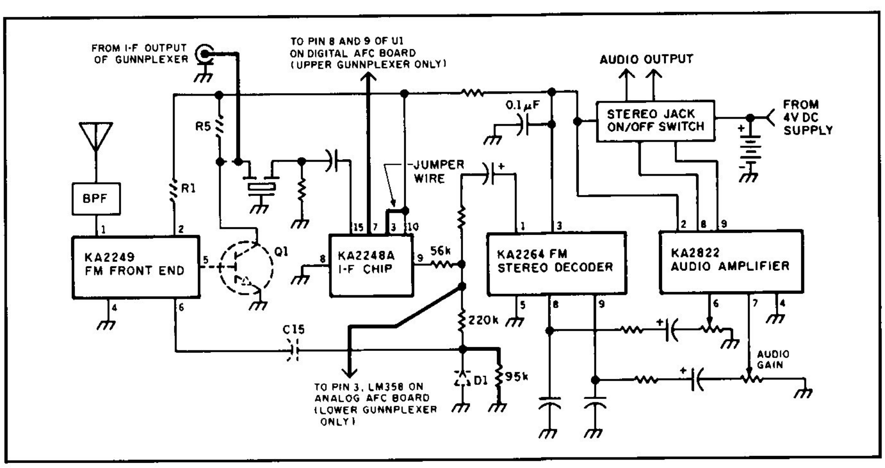


Figure 7. Partial schematic of the AS10K FM portable radio showing the modifications necessary to interface with a Gunnplexer. Added modifications are in bold, components that are removed are shown by dashed lines.

constants set by the 100-k resistors. The slow time constant (47-μF capacitor) prevents the circuit from starting to scan if there's a temporary loss in lock when, say, a bird flies through the beam or wind buffets the dish antenna. The fast time constant (0.3-μF capacitor) sets the amount of time after a signal is found before the scan stops. This lets the circuit scan into the middle of the analog lock range before stopping, as opposed to stopping right at the edge where the signal first appears.

AS10K modifications

Figure 7 gives the modifications you must make to the AS10K. The circuit board is very crowded, so you'll find some type of magnifying lens (like a 10X microscope) and a low-wattage soldering iron (12 to 15 watts) helpful for some of the work.

- Short out the on/off switch located in the headphone jack. Use a multimeter to locate the switch terminals on the PC, then solder a wire across them.
- Disconnect power from the KA2249 FM front end chip by removing R1, a 4.7-ohm resistor. The 4.7 ohm also supplied +V to pin 3 of the KA2248A chip so, to put +V back on pin 3, run a jumper wire from pin 10 to pin 3 of the KA2248A chip.
- Connect coax to the crystal filter. Make room for the coax by removing the components in line between the KA2249 chip and the crystal filter. These are R3, R5, Q1, C5, and C9. Run a length of coax (RG-174/U) from the filter input to a BNC jack mounted on the side of the enclosure.
- Tap off an AFC control voltage. Remove tuning diode D1. Replace with a resistor in the 90 to 100-k range. Run a wire from the top of the 220-k resistor to the analog AFC circuit (pin 3 of the 358 in **Figure 5**). Do this only for the Gunnplexer tuned to the "lower" frequency.
- Tap off a "lock found" signal. In most FM radios, this signal is the one that drives the tuning LED. It goes to a digital low (0 volts) when a signal is present. Connect a wire from pin 7 of the KA2248A IF chip to the digital AFC circuit (pins 8 and 9 of U1 in **Figure 6**). Do this only for the Gunnplexer tuned to the "upper" frequency.
- Set the mono/stereo switch to mono.
- Connect the audio and power. Cut the headphone cable to a convenient length, and run it to an audio jack of your choice mounted on the side of the enclosure. Connect the wires for the battery to the +4 volts DC power supply.

As AS10K radios may not be available in some locations, it's useful to look at the functions inside the KA2248A FM IF/AM chip with an eye to modifying other FM/AM portable radios. **Figure 8** is a block diagram of the chip taken from the Samsung data book. The IF signal input to the chip is FM IN (pin 15). After amplification, the signal is fed into a quadrature detector. Coupling capacitors aren't present at the output of the detector, and this allows both DC and audio components to be sent to AF OUT (pin 9) via a buffer amplifier. The detector output is also used for AGC and the LED DRIVER function. To modify other types of FM radios, locate the detector output before the blocking capacitor and connect it to the AFC circuit as described in the fourth step of the AS10K radio modifications. Be sure to have some type of resistor divide circuit [56 k/(220 k + 95 k) in **Figure 8**] to knock the change in the DC voltage down to a level suitable for the Gunnplexer. Also check the logic supplied to the signal LED with a voltmeter. The LED IND (pin 7) of the KA2248A goes to logic 0 when a signal is found. Some radios may have a logic 1, which means you should remove one of the inverting gates in the digital AFC board (connect pin 4 of U1 to the 555 instead of pin 3).

Construction and alignment

There's very little that's critical in the construction of the system. We removed the AS10K boards from their plastic cases, added the modifications, and mounted them – along with the AFC circuit boards – with 0.5-inch standoffs in metal boxes (see **Photo B**). We used BNC connectors and coaxial cable to connect the IF, baseband, and 12 volts to the Gunnplexers. The AFC circuits were built on a couple of pieces of scrap experimenter's pc board (Douglas Electronics Vector Board). Stranded wire from a section of ribbon cable interconnects the AS10K and the AFC boards. We also built a +4 volt power supply for the AS10K on each AFC board. The power supply design (shown in **Figure 9**) was based on what we had in the junkbox. Almost any circuit will work, as long as it's well filtered and can supply at least 50 mA. Dig up a pair of microphones, speakers, and 12-volt (1.5-amp) power supplies from the junkbox and the system is ready to go on the air.

Alignment is a two-step process. You begin by aligning the Gunnplexers. **Appendix A** lists the steps we used. Hopefully, your Gunnplexers will already have been aligned at the factory, because some fancy microwave equipment is required for alignment. The only difficulty you may have with a pair of pre-tuned Gunnplexers will be that the manufacturer usually sets the IF frequency to 30 MHz. You can, however, use the mechanical tuning screw on the side of

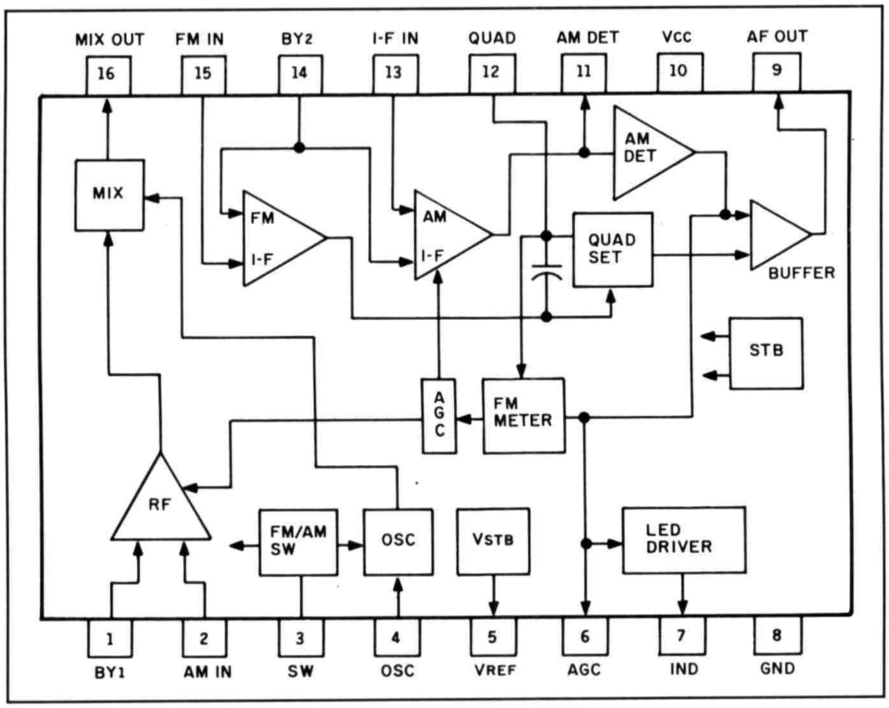


Figure 8. Block diagram of the KA2248A FM/AM IF chip.

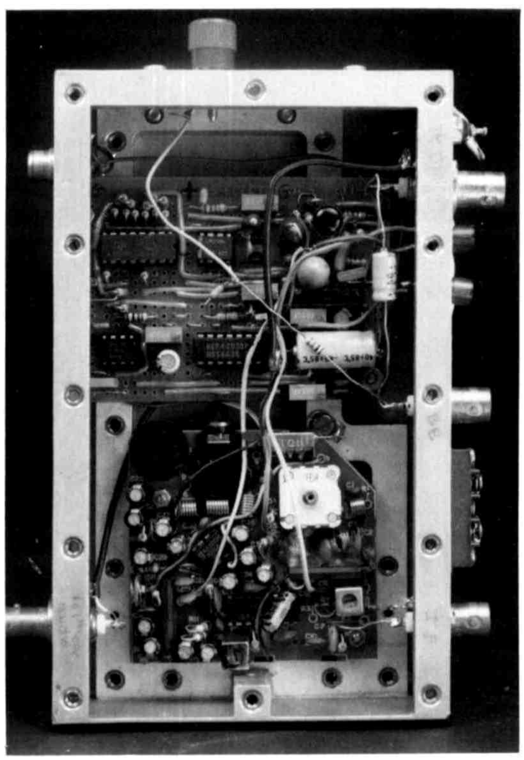


Photo B. The AS10K and digital AFC board installed in a metal housing.

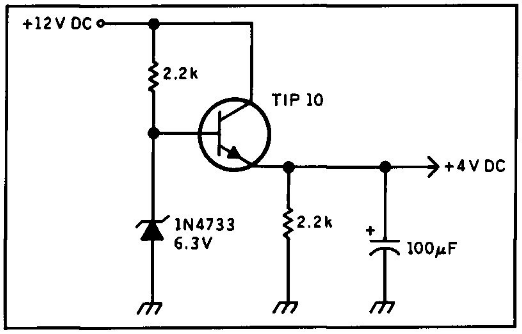


Figure 9. Schematic for the +4 volt supply. Each AFC board has one of these supplies on it to power the AS10K board.

the Gunn oscillator to change the IF to 10 MHz (the tenth step in **Appendix A**). First, power up the Gunnplexers with the 12-volt supplies and place identical DC voltages of, say, 6 volts-DC on each baseband input. Connect a frequency counter at the IF port, aim the Gunnplexers at each other, and observe the IF frequency. Now adjust the mechanical tuning screw very slowly, until the frequency counter reads 10 MHz. If you happen to pick the "upper" Gunnplexer, you'll notice that the screw will have to be turned in slightly (clockwise), while the "lower" unit will require that you back the screw out a bit (counter-clockwise). Mark the Gunnplexers, so you'll know which Gunnplexer to connect to the digital and which to connect to the analog AFC board.

Continue the alignment procedure by adjusting the trimpots on the AFC boards. On our unit, the trimpot on the analog AFC board is set to filter out signals above 10 Hz; however, the system didn't seem to be very sensitive to its setting. The trimpots on the digital AFC board require more care in adjustment. The scanning voltage range is set by the 1-k resistors at the base of Q4 and Q5. The lower voltage – set by Q5 – should be high enough that the system doesn't try and lock up at its image frequency; that is, at the frequency where the "upper" Gunnplexer is actually 10 MHz below the "lower" Gunnplexer, instead of 10 MHz above it. Four volts at the emitter of Q5 should be sufficient. The upper scan voltage is set to ensure that it isn't possible to damage the varactor in the Gunn oscillator by an overvoltage condition. Adjust the 1-k resistor at the base of Q4 so there's no more than 10 volts available there. We set the scan start trimpot to a 1.5-second delay. We found that adjusting the speed of scan, as set by the 500-k resistor on the 555, so it took 1 to 3 seconds to scan through the voltage range worked best. Some tinkering will be necessary between the 500-k scan speed and the 100-k scan stop, as the two settings interact with each other. The best way to set the scan stop is to put a voltmeter at pin 7 of the KA2248A chip, drop the lock (aim one of the dishes away for a moment), and bring it back up to check to see if the voltage is in the middle of its range as shown in **Figure 2**. The 50-k trimpots at the audio inputs on both boards should be set so the audio signal going into the baseband input is on the order of 10 to 15 mV.

Once aligned, operation couldn't be simpler. Aim the two dishes at each other and turn on the 12-volt power supplies. The digital AFC board will find the lock automatically, and the analog AFC will keep it there. Adjust the audio volume to a comfortable range and QSO away.

Conclusion

So there you have it: a way to get a pair of Gunnplexers on the air with high quality audio, but without building a lot of IF/AF stuff. Because we were given the Gunnplexers, the project was inexpensive, too. It cost the club $26 for the two FM portables; the rest of the parts were scrounged from various junkboxes. The link has found a variety of uses here at the club. Probably the most fun we've had, besides putting it together, has been to use the system for demonstrations and lectures on ham radio. We also used the system to connect the phone line at the club room up to our remotely located repeater. The KA2264 stereo decoder chip on the AS10K board proved ideal for this application. With the mono/stereo switch in stereo position, the stereo LED indicator (pin 6) lights up every time a 19-kHz stereo pilot tone is present. We installed a 19-kHz oscillator at the repeater site which is controlled by the repeater's computer. The 19-kHz oscillator turned on every time someone wanted to use the phone patch. At the club room, we tapped off the signal that lights up the stereo LED to a relay driver. The relay connected a Heathkit phone patch to the phone line. The net result was a phone patch via 24 GHz! Whatever application you have in mind for a pair of Gunnplexers, we're sure that the W2CXM system will help you get the job done.

Acknowledgments

Many thanks to Dennis Cleary, WA2PKP, for donating the Gunnplexers and Professor Rick Compton of the Electrical Engineering School at Cornell University for letting us use equipment in the microwave lab. ■

Reference
1. *The 1990 ARRL Handbook*, ARRL, Newington, CT, pages 32-15 to 32-21.

APPENDIX A: 24-GHz Gunnplexer alignment procedure

- Connect a WR-42 matched load to the antenna port.
- Adjust the Gunn oscillator power supply for the proper Gunn diode bias voltage, as specified on the oscillator (5.5volts DC typical). Set the varactor voltage to 6-volts DC (middle of the 2 to 10-volt tuning range).
- Disconnect the mixer/IF preamplifier assembly from the circulator.
- Connect a WR-42 10-dB coupler to the circulator. Connect a frequency counter to the coupled arm and a power meter to the through arm.
- Adjust the waveguide tuning screw for +5 dBm LO power at the mixer port. Set the Gunn oscillator mechanical frequency screw to the desired operating frequency (clockwise lowers frequency, counter-clockwise raises frequency). Readjust the waveguide tuning screw for +5 dBm at the mixer port if necessary. There may be some frequency pushing/pulling due to the tuning screw.
- Power down the Gunnplexer. Disconnect the coupler from the circulator and reconnect the mixer/IF preamp assembly.
- Disconnect the matched load from the antenna port and connect a power meter. Power on the Gunnplexer and check the transmitted output power (+18 dBm typical). If output power is low, check to be sure the Gunn diode bias voltage is correct, and verify that the power at the mixer port is +5 dbm. Power down the Gunnplexer.
- Align the other Gunnplexer as described in the preceding seven steps. Be sure to offset the operating frequency by the IF frequency.
- Connect the two Gunnplexers together through a 40-dB WR-42 attenuator.
- Connect a spectrum analyzer or frequency counter to the IF output BNC connector on one of the Gunnplexers. Make sure 6-volts DC is set on both varactors. Verify that the IF frequency is correct based on the difference of the Gunnplexers frequency set in the fifth step. If the IF frequency is incorrect, carefully readjust the tuning screw on one of the Gunnplexers.
- Using a spectrum analyzer or power meter, verify that the receiver conversion gain (RF to IF) is approximately 12 dB (11-dB conversion loss + 23-dB gain in the IF preamp). Note that the receiver input power is 40 dB down from the output power of the transmitting Gunnplexer. If the gain is low, check that the IF preamp bias voltage is 12-volts DC. Verify that the IF preamp gain is ≃23 dB. If all the above are correct, the mixer diode is probably damaged and needs replacement. Check that the LO power at the mixer port of the circulator is +5 dBm.
- Repeat the preceding two steps for the other Gunnplexer.
- Power down the Gunnplexer and reinstall the antennas.