Microwave intruder alarm

Construction of Doppler radar to detect movement

by M. W. Hosking, M.Sc., M.I.E.E., *British Aircraft Corporation*

Based on the Doppler frequency shift principle, this domestic intruder alarm system uses straightforward and simple techniques, together with materials that are readily available to everyone and brings what has hitherto been a costly and professional system within the reach of a domestic budget. Most of the components can also be used to make a simple voice communications link, with the main addition of an audio modulator. Construction of a voice link, including the microwave transmitter and receiver will be described in a later article.

The microwave transmitter and detector circuits are constructed in waveguide. But, for those who do not wish to go to the lengths of building these components, a complete intruder alarm kit is available with these items already built and set to the correct frequency. This complete system has been given type approval by the British Home Office as satisfying their transmission regulations.

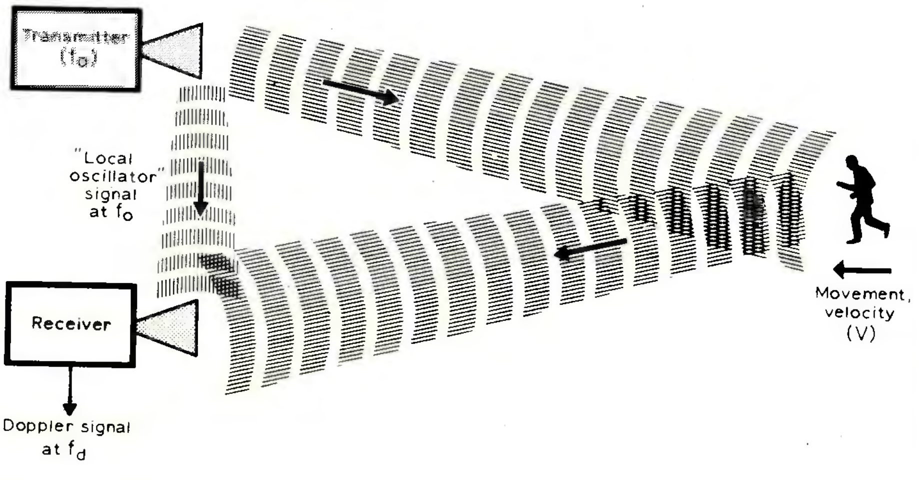
General principles

The microwave intruder alarm operates on the principles of a small radar system. It transmits a signal at the appropriate frequency which travels outward as a radio wave until it meets an object, whereupon a portion of the signal is reflected back again toward the receiver. If this returned signal can be detected and suitably processed, then information can be extracted about the reflecting object.

With the advent of solid-state sources of microwave signals ("Realm of microwaves" *Wireless World* Feb. 1973) the way has opened for very small, cheap, low-power transmitters operating from low-voltage, d.c. power supplies. In this instance, the transmitter is a Gunn diode operating from a 7V rail. The device is encapsulated in a package about the size of a match head, but to control the frequency spectrum and to extract power efficiently, it is mounted in a waveguide resonant cavity. The detector, a Schottky barrier diode, is also waveguide-mounted. Further details, including a method of fabrication for those who wish to build their own will be given in a later article.

If the reflecting object shown in the schematic arrangement of Fig. 1 is moving toward or away from the receiver then, in similar fashion to the train-whistle example usually cited at school, the receiver frequency will differ from that transmitted. The difference between the two is the Doppler frequency. In addition to the directly transmitted signal, a small portion is arranged to couple directly into the receiver and acts as a local oscillator drive. The returning frequency-shifted signal at frequency $f_o \pm f_d$ is thus mixed with this local oscillator at frequency f_o and the output circuit bandwith adjusted to extract the beat frequency difference, f_d.

Fig. 1. Principle of the c.w. Doppler radar wherein the transmitter is also the local oscillator.



The creation of a Doppler shift in frequency can be visualized by considering the two waveforms in a little more detail. As the transmitted signal moves out, with its amplitude varying sinusoidally, its phase angle relative to the starting point will change by 2π radians (360 degrees) every time the distance increases by a wavelength. In this case, the wavelength is about 28mm. Exactly the same thing is happening to both the returning signal and to that forming the local oscillator. These two are mixed together in the diode to form the beat or difference frequency.

The amplitude at this i.f. is a phase function of the two input signals. If the path, 2R, traced by the reflected signal was half a wavelength different than that taken by the direct local oscillator wave, then the two would subtract at the receiver. The output would not actually go to zero, as the two signals are not normally comparable in amplitude, but would be a minimum. Conversely, when both inputs had traversed an integral number of whole wavelengths, they would combine in phase to produce an i.f. output of maximum amplitude. If the reflecting object happens to be moving, then the relative phase of the two inputs is also changing. The local oscillator path remains constant, but the path taken by the radar signal is varying at twice the reflector speed, 2Vm/s.

Back at the mixer, the effect is as if the two wavetrains were sliding past each other at $2V/\lambda$ wavelengths per second to produce an alternating output voltage at this rate as they reinforced or subtracted from each other. This is the Doppler frequency $f_d = 2V/\lambda$

To comply with the regulations, the transmitter must operate at 10.687GHz i.e. $\lambda = 28.07$mm. Thus, the Doppler frequency is 71.25Hz for each m/s of reflector speed, or 31.85Hz per mile/h. Fig. 2 shows this relationship in graphical form.

Extraction of this Doppler signal can be used as an efficient means of detecting a moving object against a stationary background. For use as in intruder alarm, the reflections from walls and furniture will all be stationary in phase difference and so will produce no alternating beat frequency, whereas a moving object will generate an i.f. typically in the low audio range. This signal can then be amplified and used to trigger an alarm. This type of system thus gives the type of selectivity that is required and, operating as it does in this relatively uncluttered area of the frequency spectrum, is not so vulnerable to interference. There are no beams to break, as in some systems, as the signal fills the whole room and movement anywhere can trigger the alarm. Nor is it sensitive to spurious acoustic noises as are another class of alarm systems. A gain control on the alarm allows the triggering threshold to be adjusted to suit the size of room and the reflecting target, i.e. to choose the larger reflection from a human as opposed to that from the the domestic pet.

Transmitter and receiver

The general design of the transmitter and receiver cavities for the ready-made Mullard CL8960 unit are shown in Fig. 3(a) and Fig. 3(b) the schematic electrical connections. The operating frequency is controlled by the length of the transmitter waveguide between the Gunn device and the back wall. However, insertion of the tuning screw perturbs the field within the cavity in such a way as to appear initially as an inductance and to lower the resonant frequency. The side-by-side arrangement is to allow coupling of the local oscillator signal which occurs by direct leakage into the receiver waveguide. However, the level of signal is very low at about 10μW and a small amount (30-35 μA) of forward bias is necessary on the mixer diode.

Some precautions are necessary when making the electrical connections to avoid damage to the microwave semiconductor devices. The mixer diode is easily damaged by voltage transients on the mains supplies, so it is recommended that soldering appliances be disconnected from the mains just prior to making the mixer connection and during any subsequent contact with this component. Forward bias should not be allowed to exceed 1 mA. The gunn device will not tolerate a reversed supply voltage, so check before connecting. As supplied, the mixer is fitted with a shorting wire to the case and this should be left in place until assembly is finally completed and then removed. The Gunn device appears as a dynamic negative resistance and it is possible for oscillations to be induced in the supply circuit. To avoid this, connect a small 10nF capacitor directly across the terminals as shown in Fig. 3(b).

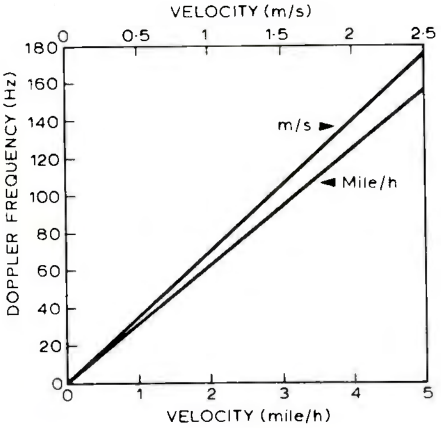
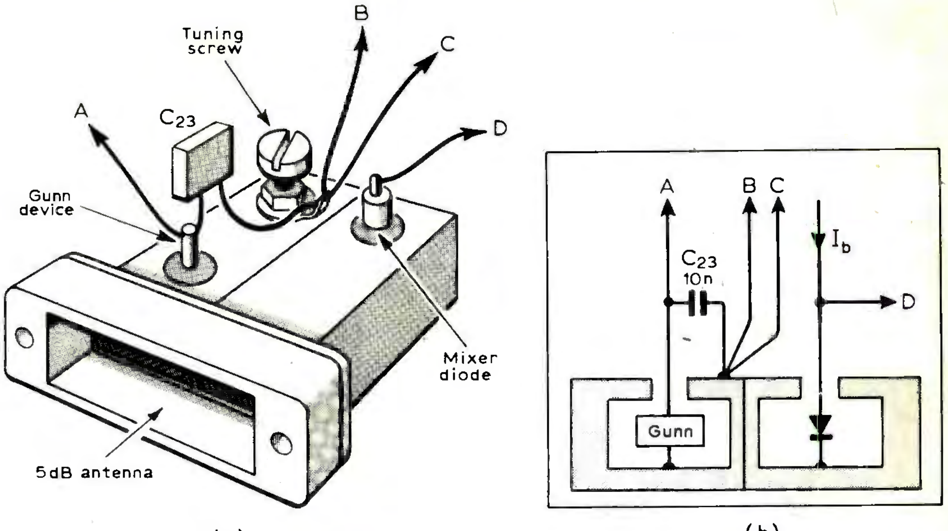


Fig. 2. Graph shows how the Doppler frequency varies with target speed for the case of a transmitter at 10,687MHz.



(a)

(b)

▲

Fig. 3. General view of the Doppler module (a) and schematic electrical connections (b)

General conditions of operation for the assembly are:

Frequency 10,687 ± 12 MHz (preset)
Gunn device supply voltage + 7.0 ± 0.1V (+ 7.5V max.)
Gunn device supply current 130 to 165mA (140mA typ.)
Mixer diode forward bias 30 to 34μA.
Power output 8mW typ. (10mW max.)

The microwave module is supplied with a small, 5-dB gain antenna, constructional details of a 20dB gain horn will be given later. The magnitude of the Doppler output at the mixer terminals is a function of the size of the reflecting object and its range. Typically, however, a man would have a radar cross section of 1m^2 and, using the 5dB antenna, the received signal would be 100 dB down on that transmitted at a range of 15m. This will produce about 40μ V of Doppler signal for signal-plus-noise to noise ratio of 18dB.

Fitted with the 5dB gain antenna, the Doppler module is reasonably matched to free space and has a polar pattern of the form shown in Fig. 4. The wide-beam coverage together with the filling-in effect from multiple reflections means that comprehensive coverage of a room is effectively achieved.

Fig. 4. Beamwidth of the Doppler module in two planes using the 5dB antenna which illustrates the wide angular coverage obtainable.

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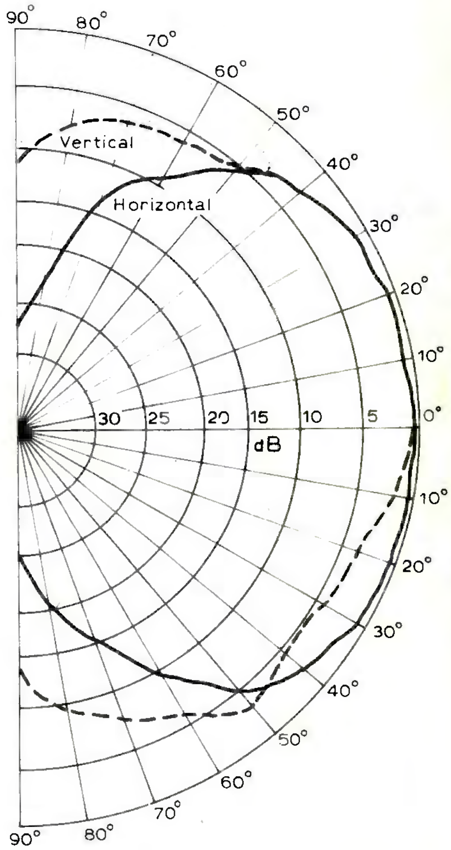

An interesting game has evolved at home: in a room about 30ft long, children endeavour to creep and crawl up on the intruder alarm without being detected. No matter how subtle the approach, this has not so far been achieved without triggering the alarm.

Receiver and alarm

It is necessary to selectively amplify the Doppler signal to a level sufficiently high to trigger an alarm, whilst at the same time rejecting false alarms from spurious noise levels (Fig. 5).

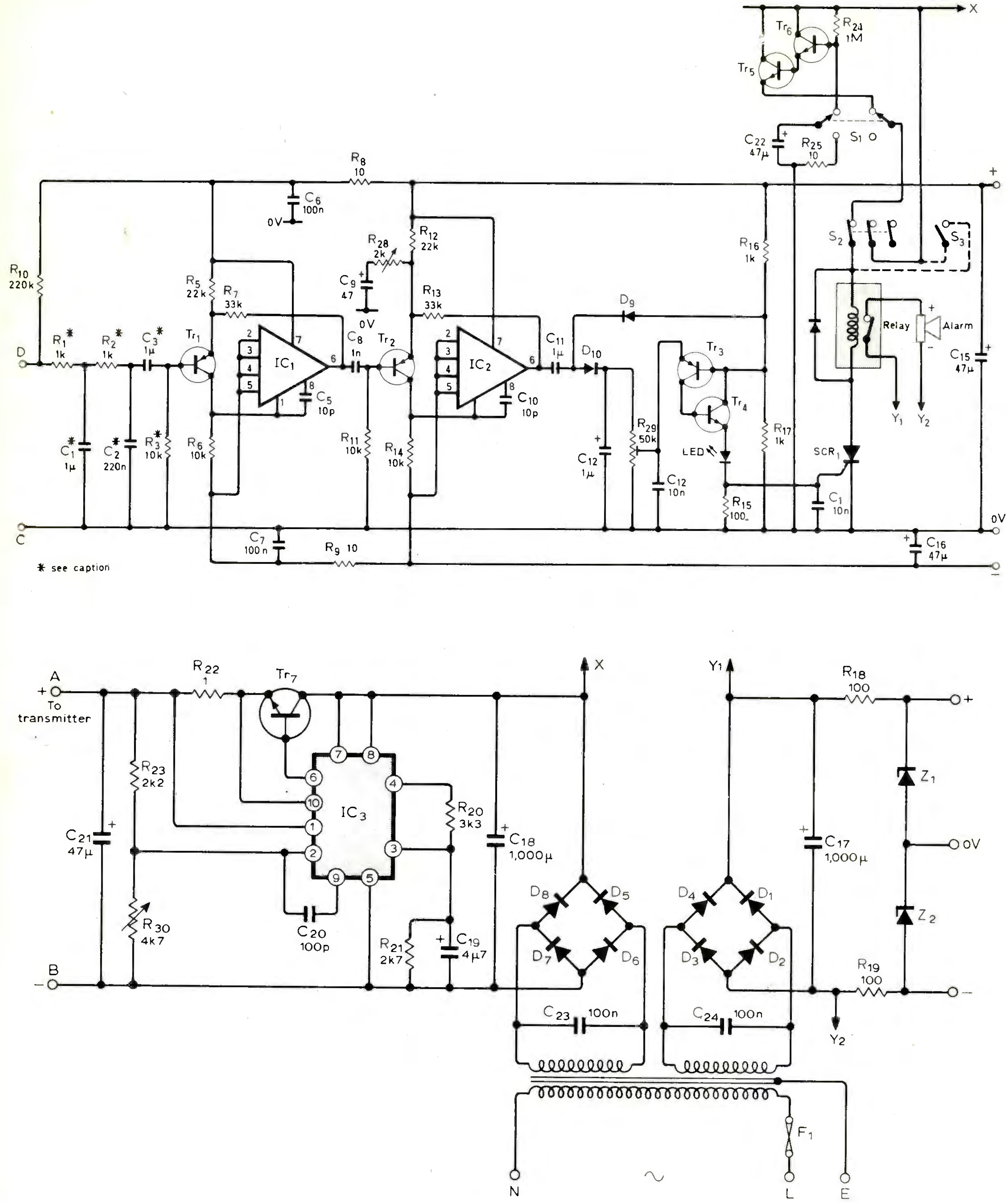

Fig. 5 (top). Amplifier and alarm trigger circuit with power supply (bottom) to p.c.b. and transmitter.

Components marked with an asterisk may have different values in the kit design.

More conventional circuits could be used for the amplifier, but the intruder system has been developed side-by-side with a voice link and as much commonality as possible has been built into the two systems.

Sensitivity of the Doppler receiver is a function of the i.f. amplifier input noise figure and bandwidth. The narrower the bandwidth, the less the contribution of thermal noise power. Thus, the first section of the circuit is an RC filter having the measured bandpass characteristic of Fig. 6. The combination of Tr_1 and IC_1 provide a first stage voltage gain of about 1000, together with a reasonable input noise figure. The slightly unusual connections to the operational amplifier are mainly for the benefit of the voice link receiver, as they provide a means of achieving a high slew rate from a normal 748 op-amp by by-passing the input stages.

Resistors: ¼-watt rating except where indicated.

R_1	1kΩ	R_{16}	1kΩ
R_2	1kΩ	R_{17}	1kΩ
R_3	10kΩ	R_{18}	100Ω
R_4	33Ω	R_{19}	100Ω
R_5	22kΩ	R_{20}	3.3kΩ
R_6	10kΩ	R_{21}	2.7kΩ
R_7	33kΩ	R_{22}	1Ω
R_8	10Ω	R_{23}	2.2kΩ
R_9	10Ω	R_{24}	1MΩ
R_{10}	220kΩ	R_{25}	10Ω, ½ watt
R_{11}	10kΩ	R_{26}	56Ω, 5 watt
R_{12}	22kΩ	R_{27}	1kΩ
R_{13}	33kΩ	R_{28}	2kΩ
R_{14}	10kΩ	R_{29}	50kΩ
R_{15}	100Ω	R_{30}	4.7kΩ

General

Transformer 6VA miniature. Two independent 12V, 0.25A secondary windings with interwinding screen.

Relay 18V, 1kΩ coil with internal diode. Contacts rated 250mA, 50V.

Alarm 18V audible warning device, 60mA mean current, 1A peak.

F_1	500mA mains fuse
S_1	miniature d.p.d.t.
S_2	3-pole screened jack plug and socket
S_3	s.p.s.t. on/off

Doppler module Mullard CL8960 or approved alternative.

Self-oscillating mixer Mullard CL8630S or approved alternative.

Capacitors

C_1	1μF	C_{14}	10nF
C_2	0.22μF	C_{15}	47μF, 10V
C_3	1μF	C_{16}	47μF, 10V
C_4	47μF, 10V	C_{17}	1000μF, 25V
C_5	10pF	C_{18}	1000μF, 25V
C_6	0.1μF	C_{19}	4.7μF, 10V
C_7	0.1μF	C_{20}	100pF
C_8	1μF	C_{21}	47μF, 20V
C_9	47μF, 10V	C_{22}	47μF, 20V
C_{10}	10pF	C_{23}	0.1μF
C_{11}	1μF	C_{24}	0.1μF
C_{12}	1μF, 16V	C_{25}	47μF, 10V
C_{13}	10nF	C_{26}	10nF

Semiconductor devices

$Tr_{1,2,3}$	ZTX 500 or equivalent
$Tr_{4,5,6}$	ZTX 302 or equivalent
Tr_7	Plastic style 3055
$IC_{1,2}$	SN72748 or equivalent
IC_3	μA 723 or equivalent
D_1 to D_8	1N4001 or equivalent
$D_{9,10}$	1N914
SCR_1	TIC44 or equivalent
LED_1	small red
$Z_{1,2}$	BZY88-C8V2

Suppliers

The system built around the CL8960 module can be obtained as a kit of parts or in ready-built form — see advertisement by Integrex.

Both kit and ready-built system have been given type approval by the Home Office for internal use on premises, under the type name Intruder 1 and have undergone thorough performance and reliability testing.

A set of two p.c.bs is available for £4 inclusive from M. R. Sagin, 23 Keyes Road, London NW2. One board accommodates the intruder alarm circuit together with the power supply components, and the second board accommodates the voice link circuit.

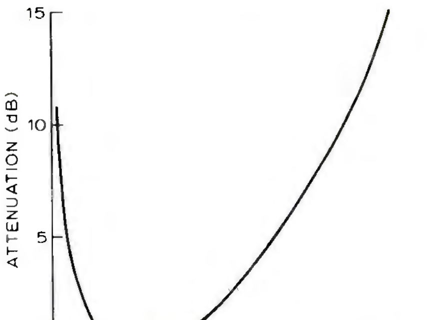

Fig. 6. Typical input filter response for the amplifier showing emphasis placed on the Doppler frequency from slow-moving objects.

The second amplifier provides a good voltage gain which can be varied with the potentiometer R_{28}. The diode pump and clamping circuit of C_{11}, C_{12}, D_9 and D_{10} defines the voltage threshold and time constant necessary to switch on the Tr_3, Tr_4 Darlington drive to fire the s.c.r. Potentiometer R_{29} provides additional control of the drive level and the l.e.d. gives a visual indication of each time that a trigger signal is generated. It is also used for initially setting the maximum gain that can be obtained from IC_2 before any instability occurs.

In the prototype, the alarm itself is an 18V audible warning device which emits a penetrating, modulated wail at about 3kHz. However, as the alarm trigger takes place through a relay, it would be a straightforward matter to connect up to other warning devices such as a door bell, or to add an extra feature such as camera and flash unit.

Assuming that the intruder alarm will be fitted in a room or hallway of domestic premises, it is obviously necessary that the circuit should be activated when everybody is out of the way, otherwise one's own movement would trigger the alarm. Two options are provided in Fig. 5 for achieving this. Firstly, the positive supply rail for the s.c.r. and relay is routed via the Tr_5, Tr_6 combination, so that sufficient current to operate the relay can only flow when Tr_5 and Tr_6 are switched on. This can only occur when C_{22} has charged through the high resistance path of R_{24}. Thus, when the overall system is switched on, the Doppler module, amplifiers and supply rails are all activated, but the relay will not operate to trigger the alarm until after a short delay. This delay is set by the timeconstant of R_{24} and C_{22} which, in this case has been chosen as 45-60 seconds: ample time to leave the room and close the door. Using this method, the alarm will be triggered on re-entering the room, say the next morning. If this was acceptable, then it could be looked upon as providing a daily check on the system.

An alternative uses the jack plug and socket arrangement. Inserting the plug by-passes the delay circuit and allows the alarm to be set by a remote switch taken out of the room and located at some convenient point. The circuit has been tested with over 100ft of flex between alarm and switch. Whichever method is used, once fired, the s.c.r. and hence the alarm will remain on until reset by the appropriate switch.

To be concluded

An end to listen-only answering machines

The proliferation of telephone answering machines is likely to advance even more rapidly if a device made by LMG Electronics gains wide acceptance. Normally the user of one of these hideously unsociable devices has to travel back to his office in order to hear the rude things people have shouted into it, but the LMG system enables an accredited caller to dial into the machine from a distant telephone and hear the messages over the phone.

According to an article by the company's founder, Mr Graham Bent, in *NRDC Bulletin* number 45 the idea is not new "but operation hitherto has been cumbersome, and only a single rewind could be initiated." The LGM device controls stop, start, rewind, playback and erase on the answering machine by means of coded pulses of tone generated by the user on a distant phone. The audible tone pulses are produced by a pocket unit the interrogator holds against the mouthpiece of the telephone he is using. One control button provides an operating code of five trains of pulses. Only this pulse can open the machine to remote operation. "There are over 40,000 possible combinations," the article says. Once the recognition code has been established the machine receives short common pulse trains enabling control of the machine from four buttons. The unit is powered from a 9V battery which should last 12 months.

When LGM approached the National Research and Development Council they asked for £3,000 repayable over 12 months but the NRDC thought they were being optimistic and lent them £4,000 repayable over three years. The loan was unsecured at 20% instead of the more usual royalty on sales. In addition the firm had £5,000 of Bent's money and a similar amount from the bank. That was in 1972. The NRDC loan was repaid "A few months ago," according to Graham Bent.